PASSER™ III-98 APPLICATION AND USER'S GUIDE

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1.0   INTERCHANGE SIGNALIZATION

This manual describes the procedural steps for using the PASSER^{TM} III-98 program to analyze signalized interchanges. It is to be used to analyze interchanges that have recently been proven to meet the *Manual on Uniform Traffic Control Devices* (MUTCD) (*1*) traffic signal warrants and are being signalized for the first time. Also, it can be used to optimize and/or retime interchanges that have previously been signalized in accordance with the MUTCD and are currently operating in such a manner as to require signal timing modification, or a combination of timing and geometric modifications.

1.1   Diamond Interchange Geometry and Phasing

This section presents a variety of information about diamond interchange geometry, typical phasing scenarios, and diamond interchange terminology.

1.1.1   Interchange Geometric Configuration

Diamond interchanges have a unique place in the order of different forms of intersection configuration and phasing. In a standard diamond, adjacent three- or four-approach (in the case of two-way frontage roads) intersections are formed by the junctions of freeway frontage roads/ramps and an arterial roadway. Other geometries and signalization scenarios result if the crossing arterial is divided at the interchange and/or if different ramping schemes are present. Schematics of different diamond interchange geometries are shown in Figure 1 below.

Full Diamond Interchange   Full Diamond Interchange w/ Frontage Roads

Split Diamond Interchange   Half Diamond Interchange
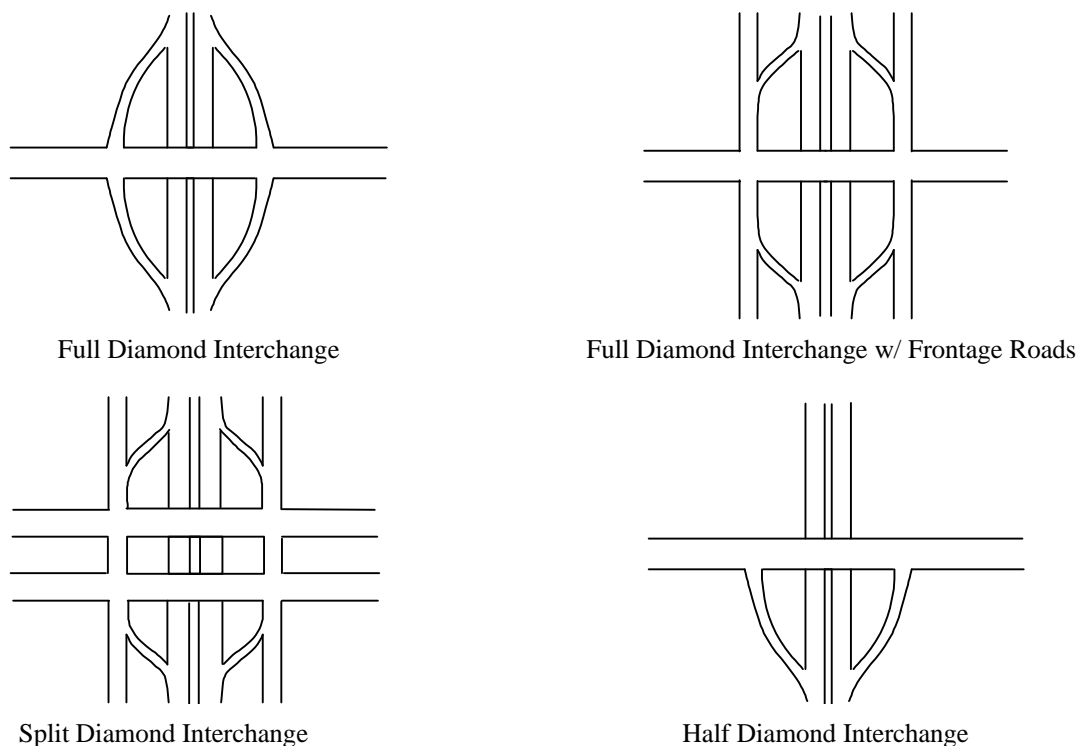
Figure 1. Diamond Interchange Configurations

1.1.2   Interchanges and NEMA Phase Numbering

The National Electrical Manufacturer's Association (NEMA) defined a method for organizing phases in a dual-ring structure as part of their Traffic Signal 1 (TS1) standard (*2*). Over the past twenty years, the NEMA phasing system and dual ring concept have become virtually synonymous with an understanding of intersection phasing. The NEMA phase reference system has been extended to diamond interchange operation. Figure 2 shows a common NEMA representation of the phases at a diamond interchange. For convenience, the phase referencing system internal to the PASSER^{TM} III-98 program is also shown.
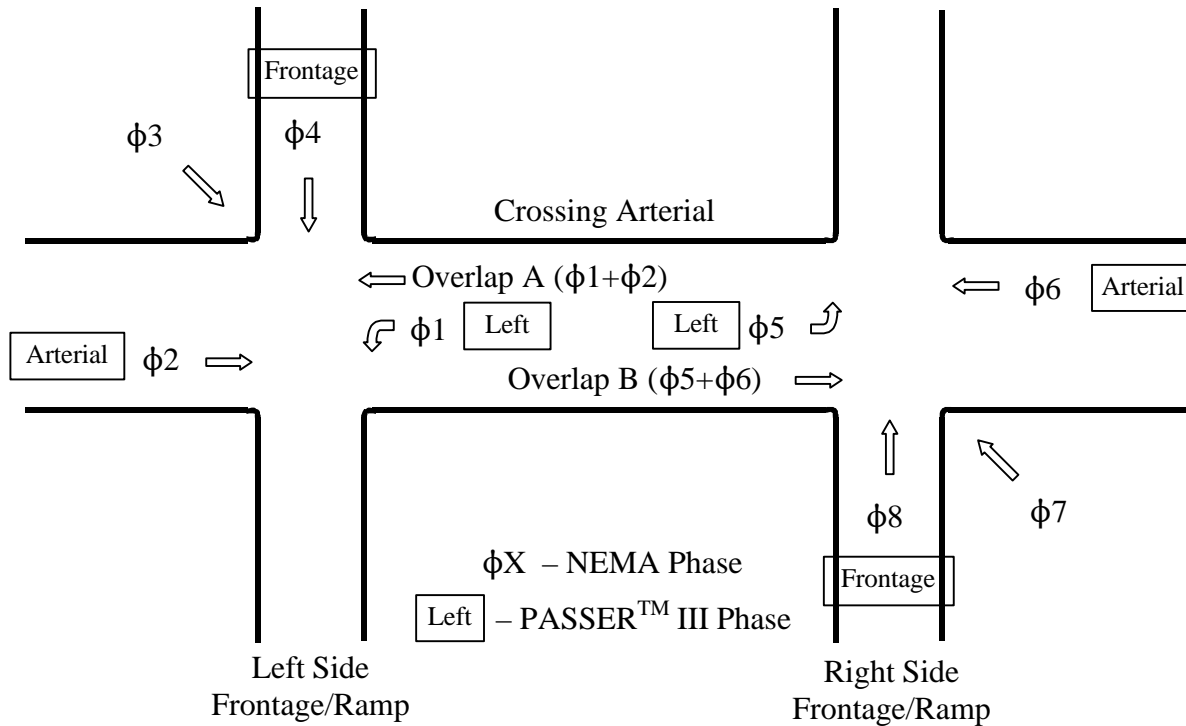
Figure 2. NEMA and PASSER^{TM} III-98 Phasing for Diamond Interchanges

1.1.3   Interchange Phase Patterns

The number of intervals and the sequence of movements at the interchange determine the interchange phase pattern, or sequence. Phasing sequence names are linked to whether or not the interior left turn precedes, or leads, the opposing through movement on each side of the interchange. The four basic left-turn sequences are:

- **Lead-lead**: protected left-turn movements from the interior lanes lead the opposing arterial movement at both intersections.
- **Lead-lag**: protected left-turn movements from the interior lanes lead the opposing arterial movement at the left intersection and lag the opposing arterial phase at the right intersection.
- **Lag-lead**: the mirror image of the lead-lag phasing pattern; and
- **Lag-lag**: protected left-turn movements from the interior lanes lag the opposing arterial movement at both intersections.

In addition to alternative phasing sequences, left-turn treatments at diamond interchanges also vary. The interior left turn movements may be protected only, protected plus permitted, or permitted only (i.e., no left turn phase). In the permitted only case, these phases would not exist (i.e., their duration would be set to zero) and the interchange would operate with only two timed phases. This alternative is desirable if a large number of acceptable gaps exist in the opposing traffic stream, and sight distance is adequate. By allowing permitted left turns, it is possible to reduce the overall delay of the interchange by reducing the number of phase changes required. Permitted left turns also increase the potential capacity of the movement by increasing the time the movement is allowed to proceed through the intersection.

1.1.4   Interchange Phase Strategies

The basic diamond interchange strategies are two-phase, three-phase, and four-phase. Each of these strategies uses a different phasing structure to serve the traffic at the interchange. A discussion of the operation of each follows.

Two-Phase

Two-phase operation can be used at diamond interchanges operating under low traffic demands. The two phases from which the strategy derives its name are the arterial phase and the frontage road or ramp phase. In this strategy, the interior left-turn movements do not have a protected phase (i.e., a left-turn arrow), but proceed permissively during the arterial phase under a green ball indication.

Two-phase operation is beneficial when the left-turn and/or opposing through traffic volumes are light; however, sufficient sight distance **must** be available to the left-turning vehicles to determine whether it is safe to make the turn.

Three-Phase

For three-phase control, the three phases are the arterial phase, the ramp/frontage road phase, and the interior left turn phase at each intersection. The two intersections can operate independently using coordination; or, the intersections can be controlled by a single controller, thus providing a more defined relationship between the intersections. Protected only or protected plus permitted left-turn movements for the interior approaches are provided. In general, three-phase operation tends to produce less overall delay (compared to four-phase operation) when there is adequate space within the interchange interior to store queued vehicles. Three-phase operation is generally recommended for interchanges with moderate to high traffic volumes, wide spacing between the two intersections, and high through volumes on either the arterial or frontage road phases.

As discussed in the previous section, the three-phase strategy allows for varying left turn sequences, including lead-lead, lead-lag, lag-lead, and lag-lag. Popular names have been used to refer to the different diamond interchange timing plans in Texas, based on figure numbers from operations manuals for the Texas Department of Transportation (TxDOT). Lag-lag timing plans are also known as "Figure 3," lead-lag is known as "Figure 6," lag-lead is known as "Figure 7,"

and lead-lead is called "Figure 4" timing. This TxDOT naming convention is mentioned for reference only, and will not be used in this guide. In the lead-lag and lag-lead variations of three-phase operation, heavy left-turn traffic from the right or left frontage roads (respectively) is allowed to progress through the interchange. Variations of the three-phase timing patterns are shown in Figure 3. All of the three-phase variations shown in Figure 3 have no restrictions on when phases can begin and end with respect to one another – any of the three phases for the left intersection can occur, in part or whole, with any of the three phases for the right intersection.

LEFT INTERSECTION   RIGHT INTERSECTION

LEAD-LEAD

LEAD-LAG

LAG-LEAD

LAG-LAG
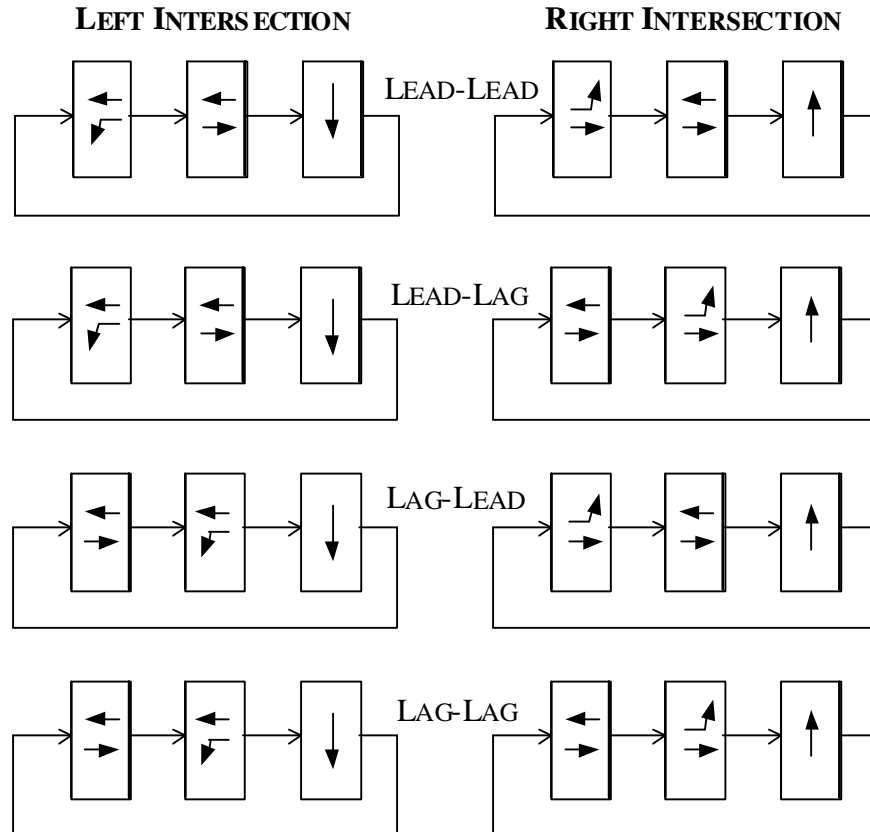
Figure 3. Three-Phase Timing Patterns

Three-phase operation should generally be used when the diamond's intersections are spaced greater than 400 feet apart, or where the interior left turn volumes of the interchange are low. With intersections spaced between 200 and 400 feet and balanced ramp traffic, three-phase or four-phase timing may be appropriate (discussed in the following section).

One form of three-phase timing, known as Basic three-phase, is defined as a lag-lag plan than has frontage road phases which are restricted to beginning and ending together. Extended three-phase operation is a form of Basic three-phase lag-lag operation wherein one frontage road movement is provided more time than the other. Figure 4 illustrates Basic and Extended three-phase diamond interchange operation.
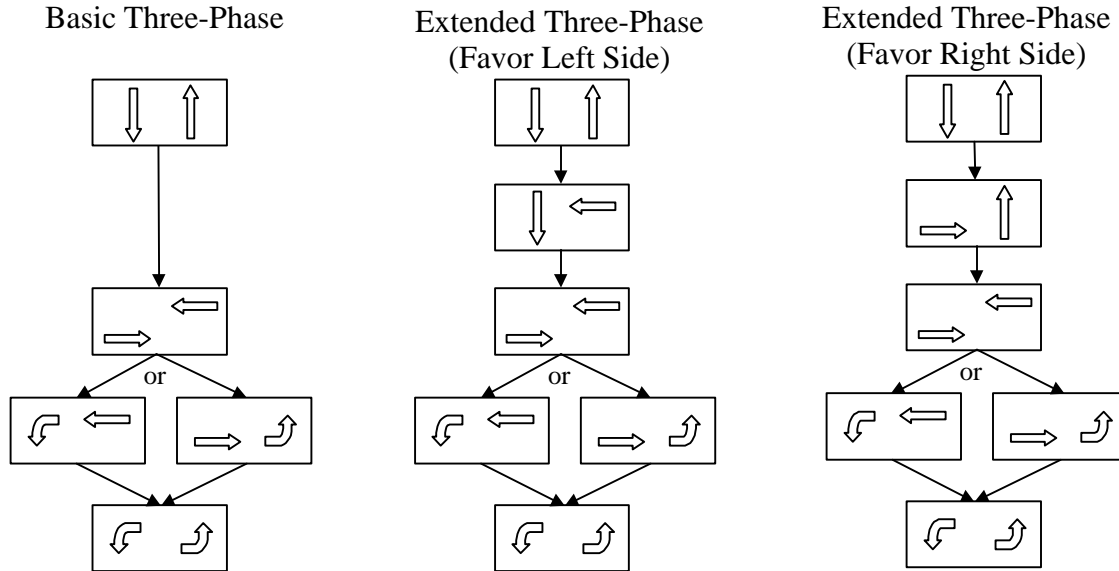
Figure 4. Three-Phase Strategies (lag-lag operation)

Four-Phase

In four-phase control, the two intersections of the interchange are operationally treated like one large intersection. The four phases that give this plan its name are the two exterior arterial phases and the two exterior ramp/frontage road phases. Protected left turns for the interior movements are provided. The duration of each interior phase is determined by subtracting the sum of the two exterior phase times at that intersection from the cycle length. This phasing pattern has become the preferred phasing plan for most diamond interchanges with close spacing (200 – 400 feet, depending on volume), and where interior turn volume intensity is high. With proper splits and offsets, it allows almost all traffic movements to progress through the interchange.

Four phase is a lead-lead timing plan, commonly with two, fixed interval transitions (also known as "travel time intervals," "internal intervals," or "fixed time intervals" and in outdated terminology – the term overlap has taken on new meaning in modern, actuated controllers - as "internal overlaps," "fixed overlaps," or "travel time overlaps"). These fixed interval transitions are related to the travel time between the two intersections. The fixed interval transitions referred to in this strategy occur when the arterial movement on one side of the interchange occurs simultaneously with the frontage road movement of the other side (i.e., the left (right) frontage road, and the right (left) exterior arterial approach). The spacing of the interchange allows these movements to be timed together for a duration no greater than the travel time between the two intersections of the interchange. The fixed interval transitions are shown in Figure 5. Four-phase plans are known colloquially as either "TTI Lead," "TTI four-phase," or a variation of TxDOT's "Figure 4."

Four-phase operation provides progression through the interchange for all major movements (with the exception of the fixed interval transition portion of interior left turn phases for frontage

road U-turns). Four-phase with two, fixed interval transition timing is common for interchanges with an intersection spacing of less than 200 feet and for interchanges with a spacing of between 200 and 400 feet that experience heavy, unbalanced ramp traffic. The phasing sequence (Figure 5) is fixed by the strategy.
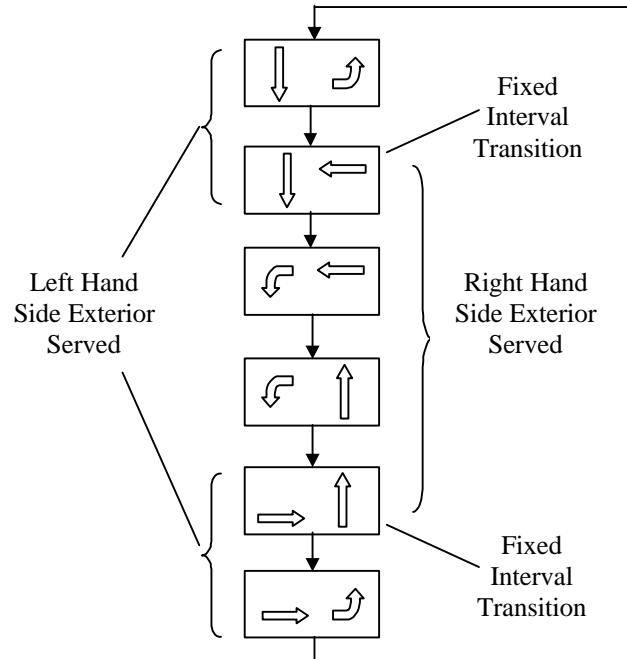
Figure 5. Four-Phase Strategy (with fixed interval transitions)

1.1.5   Operational Problems

Operational problems that are specific to diamond interchanges, their approaches, and their ramps or frontage roads include:

1. Queue spillback from one of the intersections in the interchange, which may result in the blockage of the upstream intersection by queued vehicles;
2. The left-turn lane in the interior of the interchange overflows and spills into the through lane;
3. Off-ramp queue spillback, or when a long queue of vehicles backs up into the freeway; and
4. Weaving problems on the frontage road between the ramp termini and the cross street.

One of the first signs of traffic signal operational problems is a public complaint about interchange operation. Though such complaints may be isolated events, several complaints may indicate a need for field observation and/or a traffic study. Complaints may take the form of excessive approach delay, left turn delay, poor progression, and excessive queues.

In most cases, the agency responsible for the signal operation will dispatch an analyst to verify the complaint as a legitimate problem related to the signal. Long queues, ineffective use of green time, and excessive cycle lengths might be apparent to the analyst. Solving the problem may be as simple as requesting a detector repair. If the problem is with the signal settings rather than the

equipment, a thorough study is likely to be in order. A likely result from such an effort is the modification of the cycle length, phasing split times, phase sequencing, or offset with respect to other signals.

Macroscopic roadway environment changes such as alterations in traffic flow caused by land use and population changes, addition or deletion of signals in the area, changes in major traffic generators, and roadway geometric modifications may also necessitate signal retiming. To identify operational problems before they become severe, some jurisdictions perform an annual inspection and evaluation of signal operations.

1.2   Background Information

Traffic engineering theory supports the methods and procedures for most traffic engineering analysis software. The Highway Capacity Software (HCS), for instance, is a software-encoded version of the major analysis procedures outlined in the *Highway Capacity Manual* (HCM) (**3**). Many programs, including PASSER^{TM} III-98, are based on a range of traffic engineering, optimization, and queuing theories. The most basic elements and definitions, taken from the *Traffic Engineering Handbook* (*4*) and *Traffic Engineering* (*5*), are presented here to assist in understanding the PASSER^{TM} III-98 program. Traffic controller hardware, or the devices actually used to control the signals at an intersection/interchange, are also discussed.

1.2.1   Signal Controller Types

As electronics and computer technologies have continued to evolve over time, these advancements have carried over into traffic signal controller technology to produce more reliable, flexible, and functional devices. Five types of controllers are described below. Even the oldest electromechanical controllers can still be found in the field today.

1.   Electromechanical - These devices use synchronous motors and cams to open and close electronic circuits that govern the signal indications at an intersection. They are pin programmable for such variables as cycle length and phase split; they provide the engineer with the capability of changing cycle length, split, and offset (C/S/O); and, they can accommodate changing C/S/O by time of day. Intersections with operational problems and electromechanical controllers should be considered for modernization.

2.   Type 170/179 – 170 controllers are based on a hardware equipment specification jointly developed by the states of California and New York. Buying a Type 170 controller is like buying a personal computer - you get a standard piece of electronics, but you have to buy software to make it do something useful. Several national vendors (i.e., Wapiti, BiTrans, etc.) provide a range of software for the 170. Type 170 controllers have proven extremely reliable and flexible over time, but the technology (i.e., eight-bit microprocessor) is over twenty years old. Some vendors offer updated PROM cards for the 170 that add more memory (i.e., more timing plans, more functions) and newer processors with the simple exchange of a circuit board plug-in module. Type 179

controllers are based on a specification that "updated" the 170 specification (i.e., more hardware-based processing capability and memory).

3. NEMA TS1 & TS2 - The NEMA TS1 standard came about roughly in the same time frame as the original Type 170 specification. Unlike the 170 specification, the TS1 standard defined the functionality (i.e., what the controller device was supposed to do and what features it was required to have) of the controller device rather than the equipment. The TS1 also standardized cabinet wiring and harnesses, added a conflict monitor (i.e., a cabinet "watchdog" device), and developed a uniform phase reference. NEMA TS1 compatible controllers have evolved over time because manufacturers were able to use new microprocessors and expanded memory to fulfill TS1 functional requirements, and each manufacturer was able to add additional functionality (i.e., closed loop system) to make their products more marketable. Unfortunately, each manufacturer pursued functionality outside of the TS1 standard differently, and this "higher tier" of functionality is not compatible across manufacturers. The TS2 standard is a major leap in the modernization of the TS1 for current electronics technology. Cabinet communications no longer take place using discrete electronic signals over hundreds of wires, but over a communications bus. The conflict monitor of the TS1 has been replaced by a much more powerful programmable malfunction management unit, and detection, coordination, and preemption capabilities have been enhanced. Manufacturers are also building in the capability to have modern NEMA controllers communicate using the National Transportation Communications for ITS Protocol (NTCIP).

4. Texas Diamond Controller – The State of Texas has continuous frontage roads along most of its interstate and urban freeway mileage. Because of this roadway feature, the diamond interchange is a popular interchange treatment for junctions of grade separated facilities with major and minor arterials. To cope with operating the many interchange geometries and signal orientations at these crossings, the Texas Department of Transportation (TxDOT) developed a specification for a signal controller device that was capable of operating in two of the most versatile phasing sequences common at diamond interchanges. Controllers that meet the TxDOT Diamond Specification are programmed with settings for operation in the Basic three-phase, lag-lag pattern and the TTI four-phase strategy.

5. California Department of Transportation (Caltrans), Type 2070 - Like the Type 170, the 2070 is a specification for a piece of electronic equipment. Unlike the 170, the 2070 is an open architecture device that has expansion bays for adding processing power and memory for device functionality that can pass far beyond simple traffic control. Third party software must still be purchased to run on the 2070 in order to provide traffic control functions. However, additional cards can be added to the 2070 to accomplish any number of objectives, including ramp metering control, video camera control and detection, changeable message sign control, etc. The 2070 is one example of a new generation of advanced transportation controllers (ATC).

1.2.2   Controller Modes of Operation

All modern controllers are capable of operating in one of three modes: pretimed, semi-actuated, or fully actuated.   Choice of mode is dependent on a variety of considerations, including availability of communications infrastructure (wireline or radio), traffic flow characteristics at the site, intersection spacing, detector placement, and detector maintenance.   Below are descriptions, conditions for application, and examples of each mode of controller operation.

Pretimed control is the most basic timing pattern for traffic signals. In this type of control, the controller(s) have preprogrammed phase lengths and a phase order that is executed on a fixed cycle length. Once programmed, the same order and duration of phase indications will occur at the intersection until the controller settings are manually reprogrammed, or another set of fixed duration settings is selected by time-of-day or day-of-week/month/year.   Pretimed control maintains a constant predetermined set of intervals that are provided for a fixed duration every cycle. This type of control is useful for maintaining bandwidth through an interchange, but fixed time solutions have limitations because of the changing traffic volumes that occur throughout the day.   Pretimed operation tends to be most effective where there is little or no traffic growth and traffic patterns are predictable.   Downtowns (especially due to pedestrian requirements) and smaller towns not experiencing growth are typical locations for pretimed operation.

Semi-actuated, or coordinated actuated, operation uses detectors on non-coordinated phases to offer more flexible use of green time than is possible in pretimed operation. Semi-actuated control is a type of actuated control, which maintains a fixed cycle length and allows coordination with adjacent traffic signals. In semi-actuated control, the phase times are allowed to vary to serve traffic demands. The phase times are restricted to a certain extent in order to maintain a fixed point of coordination with adjacent signalized intersections.   The primary difference between actuated and semi-actuated control is that under actuated control the cycle length of the interchange is allowed to vary based on the length of the phase times. Semi-actuated control maintains a fixed cycle and a corresponding coordination point, or offset, so that other intersections can remain "in sync" over time. Semi-actuated operation is most appropriate along arterial roadways that have a high volume with respect to crossing roadways.

Interchanges operating in fully actuated mode have no background cycle length.   One of the advantages of a single controller for diamond interchanges is the ability to operate in a fully actuated mode, without the need for a background cycle length. Fully actuated traffic control is more adaptable to the traffic conditions that exist. Actuated controllers are able to adjust phase lengths based on the traffic demand that is sensed by detectors. Detectors such as inductive loops or video imaging systems communicate the status of the detector to the controller and logic within the controller determines whether to continue the phase or reduce the time allotted to that particular phase. Detection systems and detector locations for the interchange can vary based on the type of phasing (6).

In this type of control, the number of vehicles that pass through the detection zones of traffic detectors determines phase durations (splits). A minimum and maximum time are set for each phase. The first vehicle in the queue (at the stop bar) guarantees that the minimum time will be given to the phase. Subsequent detections extend the phase for a given amount of time up until

the maximum, where green will go to the next conflicting phase that has a detection. If the maximum time is reached and no vehicles are waiting on conflicting phases, green remains on the first phase (i.e., past the max. time) until a detection on another phase occurs. This mode is appropriate where traffic volumes and patterns are reasonably to highly variable, where intersections are isolated (i.e., far away from other signalized intersections), or where quick response to a vehicle detection is desired.

1.2.3   Minimum Green Settings

In either pretimed, semi-actuated, or actuated mode of operation, each phase at a diamond interchange must be programmed with a minimum green time. The minimum time is determined based on a number of considerations, including the mode of controller and phase operation, the presence and location of detectors on the approach served by the phase, and the responsiveness of motorists using the interchange.

In pretimed operation, the minimum green time and maximum green time for each phase are often set to the same value. Thus, the minimum green is based on the timing requirements for the maximum green time, which is the traffic demand using the phase considering traffic demand and phasing requirements for all other phases. However, the minimum green time will always have a lower bound. It must be at least sufficiently long to allow motorists to recognize that the signal has gone to green and begin responding to the green signal indication (i.e., remove brake and begin accelerating). Minimum green times are usually governed by the practices of the responsible agency, but usually vary between five and seven seconds.

Controllers operating in either semi-actuated or fully actuated mode make more direct use of the minimum green time programmed into the controller for each phase. In either of these actuated modes, the minimum green time is the minimum length of time that a green indication will be displayed for each phase. The duration of the minimum green is usually based on the location of the detectors that service the phase, where the minimum green is adequate to serve all vehicles located between the stop bar and the detector location (which is usually set back from the intersection/stop bar). Some controller devices also offer variable initial (i.e., variable minimum green), which bases the duration of the minimum green on the amount of green time required to serve the number of vehicles that have crossed the detector before that phase becomes green. When variable initial is used, there is an absolute minimum green which must remain present, but the minimum green time can be extended up to the maximum initial (i.e., longest minimum green time).

Minimum green times are an especially important consideration at diamond interchanges because of phasing complexity and controller programming required to ensure proper and appropriate operation. Some diamond interchange phasing sequences, especially TTI four-phase operation, require that multiple phases be used to serve some (or perhaps, all, depending on controller configuration) interchange traffic movements. This is accomplished by using overlaps, which allow multiple phases to cause a green indication to be displayed for the traffic movement for which the overlap is programmed. The overlap will maintain a green indication for a movement during the green time, yellow change interval, and red clearance interval of the first serviced phase within the overlap if the following phase(s) are also programmed to be a part

of the overlap. However, in all diamond phasing sequences that operate in semi-actuated and/or fully actuated mode, it may be possible to skip any or all of the phases programmed to be part of the overlap. Thus, it is critical that each phase, whether it is part of an overlap or not, be programmed with adequate minimum green time, yellow change interval, and red clearance interval for the appropriate approach and movement. In practical implementation, this may mean that the interchange's cycle length must be lengthened slightly to provide all phases with a minimum green and clearance times. When implementing output and timing recommendations from the PASSER^{TM} III-98 program, it may be necessary to extend certain phase times (and, thus the cycle length) to ensure that all phases (whether they compose an overlap or not) are provided with adequate and appropriate minimum green times, yellow change intervals, and red clearance intervals.

1.2.4 Yellow + All Red Clearance

Phase termination before the start of a conflicting phase is always accomplished using a transition period that is composed of the yellow time plus the all red clearance time. Different agencies have different rules governing how these periods are computed, and in some cases all red clearance times are set to zero. NEMA also influences phasing behavior within controller devices that meet its standard by requiring that all phases have a yellow change interval of at least three seconds (*2*). The following equations from the *Traffic Engineering Handbook* (*4*) present means for computing the yellow and all red clearance times, respectively.

$$y = t + \frac{v}{2a + 2Gg} \tag{1}$$

where: y = length of the yellow interval, to the nearest 0.1 second
t = driver perception/reaction time, recommended as 1.0 second
v = velocity of approaching vehicle, in feet/second
a = deceleration rate, recommended as 10 feet/second^2
G = acceleration due to gravity, 32 feet/second^2
g = grade of approach, decimal format (0.02 for 2%, downhill is negative)

$$\begin{array}{ccc} (2) & (3) & (4) \\ \\ r = \dfrac{W + L}{V} & r = \dfrac{P}{V} & r = \dfrac{P + L}{V} \end{array}$$

where: r = length of red clearance interval, to the nearest 0.1 sec
W = width of intersection, in feet, measured from the near-side stop line to the far edge of the conflicting traffic lane along the vehicle path
P = width of intersection, in feet, measured from the near-side stop line to the far side of the farthest conflicting pedestrian crosswalk along the actual vehicle path
L = length of vehicle, recommended as 20 feet
V = speed of vehicle through the intersection, in feet/second

All red clearance equations depend on the type of application, where (*4*) states that it is recommended to use Equation 2 where there are no pedestrians. Equation 3 or 4 (whichever is longer) is used where there is the probability of pedestrian crossing, and Equation 4 where there is significant pedestrian traffic or pedestrian signals that protect the crosswalk.

Appropriate detector placement combined with appropriate yellow and the red clearance time ensures that motorists are not trapped in a "dilemma zone." The dilemma zone is a point where a driver cannot stop at a reasonable rate of deceleration and where the same driver cannot pass through the intersection within the yellow time allotted. The red clearance interval is primarily a tool to avoid displaying unusually long yellow times. For more information, see reference (*5*).

1.2.5   Pedestrian Treatment

The MUTCD (*1*) states that "under normal conditions the WALK interval should be at least 4 to 7 seconds." In addition, the MUTCD indicates that the <u>minimum</u> pedestrian walking distance to be used in computing pedestrian green requirements is the distance to the middle of the farthest traveled lane (Figure 6, D_1). The distance pedestrians must travel to cross the intersection is the main criteria for selection of a minimum pedestrian time at the intersection. Figure 6 shows the various points that distances can be used for the computation of pedestrian walking distance; prevailing site conditions and engineering judgement will play a part in determining which distance is most appropriate for the selection of a minimum pedestrian time.
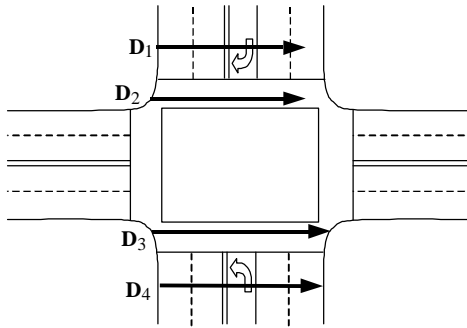
Figure 6. Walking Distances for Pedestrian Clearance Calculation

Once an appropriate distance is selected, Equation 5 is used to compute pedestrian time.

$$G_P = \text{Ped}_{min} + \frac{Distance}{W} \tag{5}$$

where: G_p =   pedestrian time
Ped_{min} =   minimum pedestrian "WALK" display, varies by agency
Distance =   distance measured in feet, using appropriate distance (D_1, D_2, D_3, D_4) from Figure 6, with D_1 being the minimum.
W =   walking speed in feet/second; 3.5 and 4.0 are commonly used; when pedestrian speeds are lower (school age, elderly or handicapped pedestrians), speeds should be reduced.

Figure 7 relates how the pedestrian time minimums may influence signal timing where the minimum time required for vehicles is shorter than the minimum time required for pedestrians.
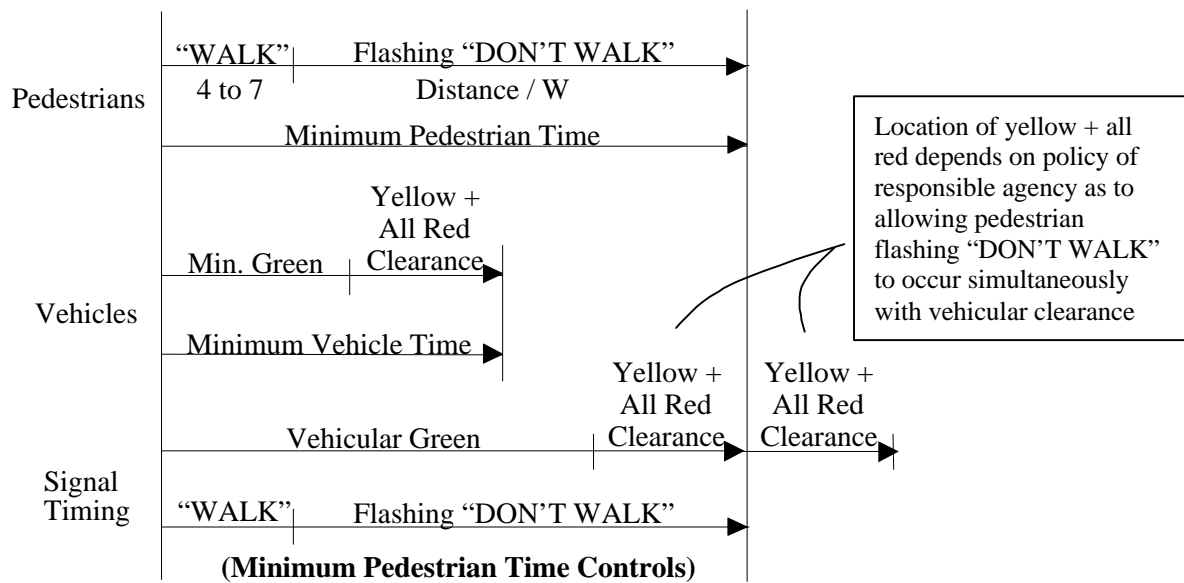
Figure 7. Demonstration of Minimum Pedestrian Versus Minimum Vehicular Times

It is important to consider that if pedestrian push buttons are not present and pedestrian activity is probable, the minimum green + yellow + all red displayed for the through phase must be at least as long as the minimum pedestrian time, G_p, of the parallel pedestrian movement. When push buttons are present, the pedestrian "WALK" and flashing "DON'T WALK" times entered into the controller are subject to the same minimum requirements presented and calculated in this section. If computed pedestrian minimums are longer than vehicular minimums, the longer of the two minimums will control and should be entered. Some jurisdictions allow timing the pedestrian flashing "DON'T WALK" interval to time concurrently with vehicular clearance times; others do not.

1.2.6   Traffic Detection at Signalized Interchanges

In either semi-actuated or actuated modes of operation, signal controllers require information about traffic approaching the interchange. Devices, known as detectors, provide this input to the signal controller. A variety of detectors are applicable, but the most common is the inductive loop detector, or simply "loop." The loop itself is 2 or 3 turns (depending on loop length and environment) of wire placed in a sawcut in the pavement along the approach to the intersection/interchange. Wire leaders connect the loop to an amplifier, which is then connected to the controller. Loops and/or loop systems can be designed to cover multiple approach lanes.

Depending on approach speed, single or multiple loops may be used within a lane. Detectors can be operated in either presence or pulse mode. In presence mode, the amplifier sends the controller a "call" at all times when a vehicle is detected over the loop. In pulse mode, a short

detection is sent to the controller following a vehicle arrival at the loop. At virtually all signalized intersections, detectors are operated in presence mode.

Another feature of detector operation is that detection can be set in locking and non-locking memory modes. Under locking memory, a detection call is "remembered" by the controller until the phase called by that detection is serviced. Under non-locking memory, the controller only registers a call when a vehicle is over the sensor. An example of the usefulness of this mode is right-turn on red (RTOR) situations, where the vehicle is effectively "forgotten" if it is able to make a safe RTOR maneuver.

The Texas Department of Transportation (TxDOT) has developed common detector placements for the three- and four-phase control patterns.

Three-Phase Control

The operational practices for use with three-phase control are presented below. A long (i.e., 6'X 40') rectangular shaped inductive loop detector is used in the interior of the interchange for left turns. The through lanes are equipped with 6' X 6' loop detectors spaced 200' in advance of the stop bar. The placement of the detectors along the arterial and frontage road/ramp approaches is dependent on speed. Stop bar detection is made possible by a 6' X 40' loop in each lane. Stop bar detection is augmented by advanced detectors (usually measuring 6' X 6') placed in each lane. The advance detection placement is dictated by the speed of approaching traffic. Table 1 shows setback distances that have been computed for use with 6' X 40' stop bar loops under a three-phase control strategy. Figure 8 illustrates the resulting detector layout for a diamond interchange under three-phase control.

Table 1. Loop Setback Distances for Three-Phase Diamond Operation

Speed (mph)	First setback loop distance, S1 (ft)	Second setback loop distance, S2 (ft)	Third setback loop distance, S3 (ft)	Passage Time (sec)
30	100	n/a	n/a	2 to 3
35	135	n/a	n/a	2 to 3
40	170	n/a	n/a	2 to 3
45	210	330	n/a	2.0
50	220	350	n/a	2.0
55	225	320	415	1.2

Note: All setbacks in this table are for use with 6' X 40' stop bar loop.
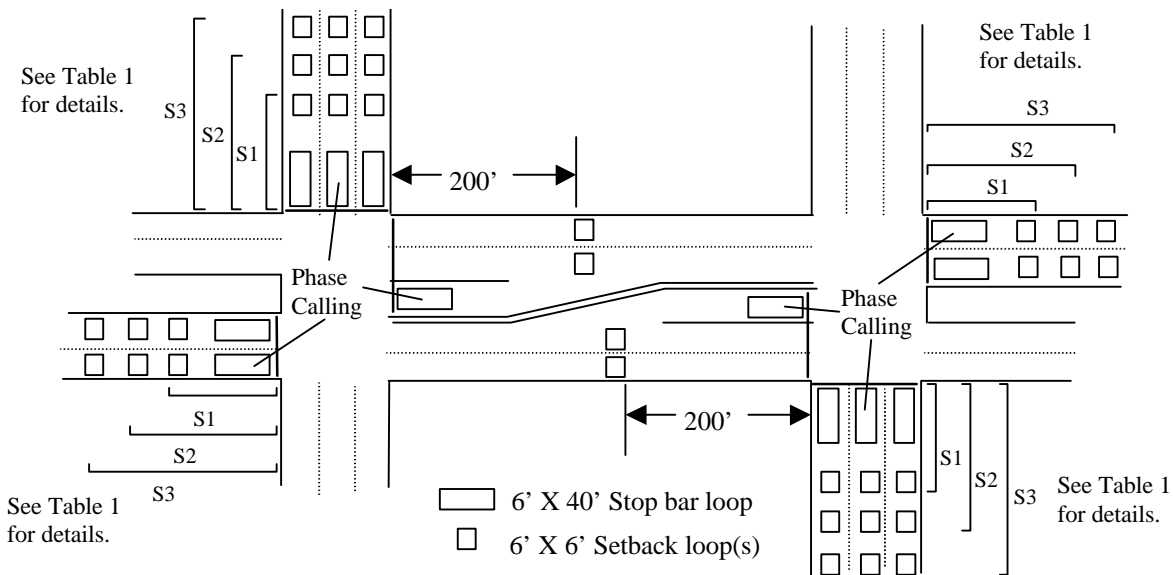
Figure 8. Typical Diamond Interchange Detector Layout for Three-Phase Operation

Four-Phase Control

The detector placement is slightly different for diamond interchanges under four-phase control. Arterial detector placement is based on the same logic used above, advance detectors supplemented with stop bar detection to insure phase calls for stopped vehicles. Frontage road/ramp detector placement is dependent on clearance times and travel times within the interchange. The following procedure (illustrated in Figure 9) can be used to calculate the setback distances for frontage loops.
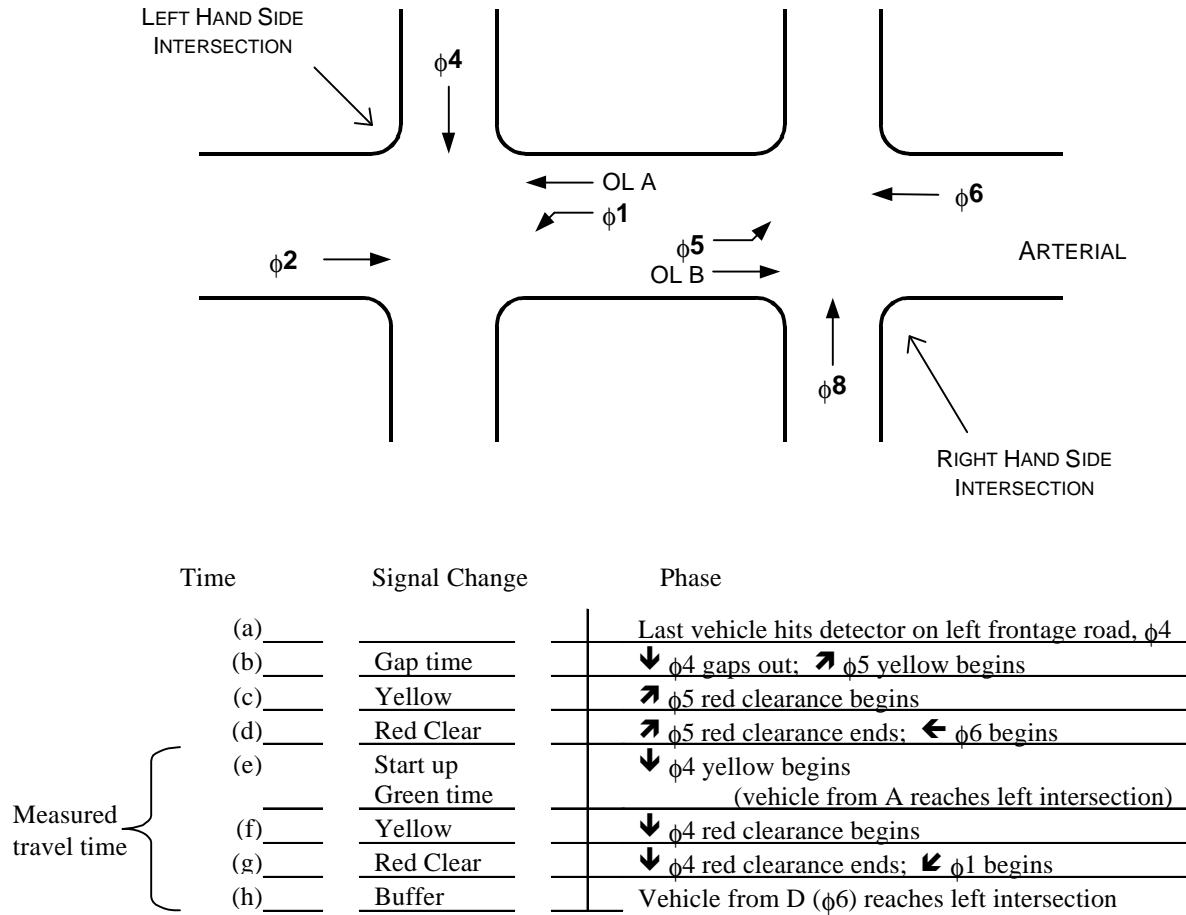
Figure 9. Calculation Procedure for Four-Phase Detector Setback Distance

where (calculated in the given order):

(a) = 0; For this example, consider (a) at time zero

(b) = (a) + gap time for $\phi4$

(c) = (b) + $\phi5$ yellow time

(d) = (c) + $\phi5$ red clearance time

(h) = (d) + measured travel time (travel time from $\phi6$ (right) to next (left) intersection)

(g) = (h) - buffer time (between frontage road phase & interior green, usu. 2-4 sec)

(f) = (g) - red clearance for (left) frontage road

(e) = (f) - yellow time for (left) frontage road

Following these calculations, the travel time from the setback detector to the ramp stop bar is calculated as (e) minus (a). The detector setback distance is computed as this travel time multiplied by the speed on the frontage road/ramp (in feet per second). If desired, two seconds can be added to the travel time (i.e., frontage road vehicle will be two seconds behind the stop

bar at the onset of yellow) to improve operational efficiency and reduce cycle length. Figure 10 shows a typical detector setup for a diamond interchange operating under four-phase control. If detector setback is compromised for practical considerations, it is important to have good gap settings and maximum times for efficiency.
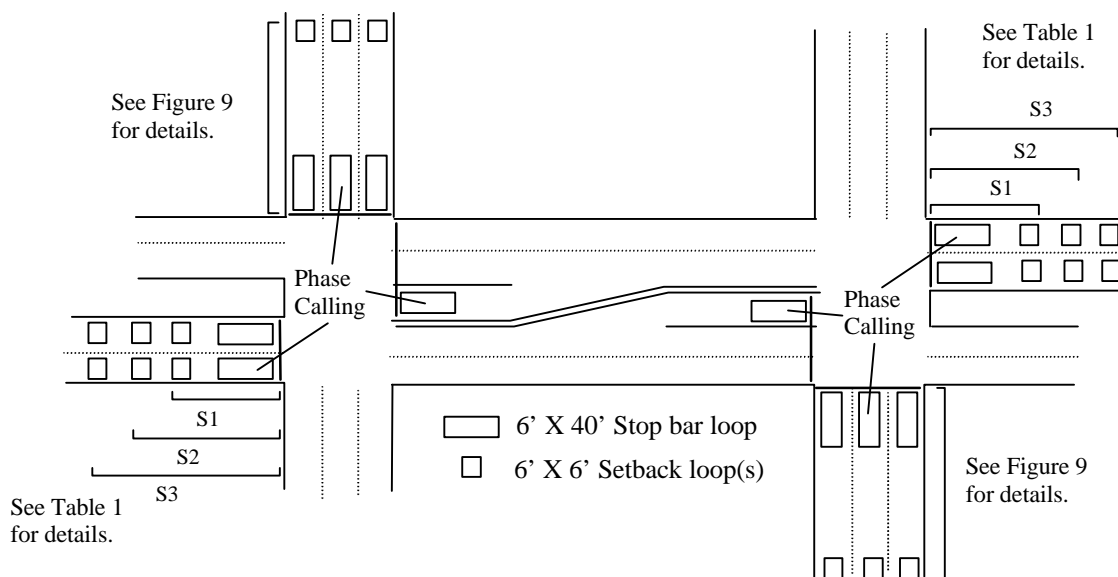
Figure 10. Typical Diamond Interchange Detector Layout for Four-Phase Operation

Both the three-phase and four-phase detector placement procedures must be calibrated based on site specific features. An additional feature of TxDOT's detector plans for interchanges is that the 6' X 40' stop bar loops may be "turned off" after: (1) the approach receives a green indication, (2) the detectors experience a gap of (usually) greater than 0.5 seconds, and (3) the other intersection's arterial phase has a detection. This procedure, known as detector switching, effectively uses the stop bar detectors to call the phase, and then turns them off so that the setback detectors can efficiently extend the phase. Without detector switching, the stop bar detectors unnecessarily extend the green beyond the time required to clear the platoon. Additional information about loop detection can be found in the *Traffic Control Systems Handbook* (*6*) and the *Traffic Detector Handbook* (*7*).

1.2.7   Optimization Methods

A variety of different methods exist for determining the optimum cycle length and phase timing splits of an signalized intersection. Optimization methods tend to differ, as do the objectives of the optimization, when it comes to providing optimal cycle, split, and offset for a system of intersections, such as an interchange. One optimization technique, known as the delay difference of offset method, is based upon empirical observation and theory that indicates that (given an appropriate cycle length and green splits) the selection of an optimal offset is an essential component in determining the minimum delay settings for an interchange. In the diamond interchange case, the offset is usually defined as the time between the start of same-direction arterial phases within the interchange. The offset in PASSER$^{\text{TM}}$ III-98 is an internal offset, as it

describes that difference in time between the start of the left (right) intersection arterial phase and the start of the right (left) intersection interior though phase. The range of the offset is limited by the cycle length, and negative offsets are converted to fit the domain of the cycle length. Research has shown that delay increases the farther the offset varies from the ideal, reaches a maximum point, and then begins to decrease until it once again reaches the minimum (at the ideal offset). Figure 11 shows both the delay offset curve for a hypothetical interchange, and examples of platoon behavior for non-ideal and ideal offsets. PASSER^{TM} III-98 uses the delay difference of offset to compute optimal offsets for interchanges.

c) delay-difference of offset relationship (60 second cycle length)
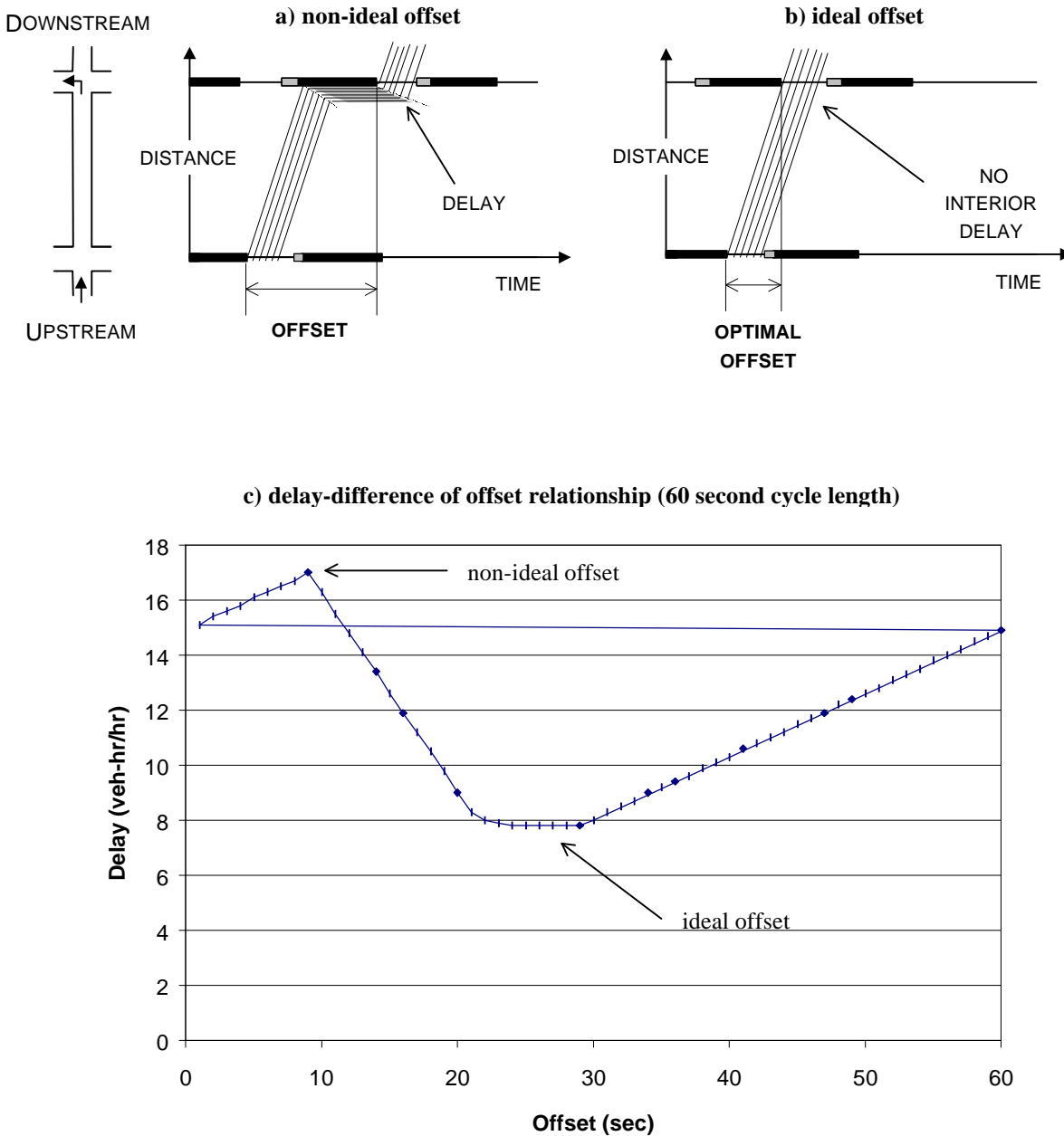
Figure 11. Offset Considerations for Diamond Interchanges

A user-selected measure of effectiveness can be minimized to determine the best solution. Common measures of effectiveness (MOEs) that can be minimized include total delay, stopped delay, fuel consumption, and emissions. One of the most common measures is stopped delay, since this MOE is linked to signalized intersection level of service (LOS) in the HCM (*3*) and provides an easily comprehensible indication of intersection and/or system performance.

Another MOE that is used in reference to diamond interchanges is storage ratio. This MOE is used to track how efficiently a timing plan processes vehicles in the interchange interior. In essence, storage ratio is the number of vehicles in, or expected to be in, the interior of the interchange divided by the available storage space. A storage ratio of greater than 0.8 indicates a potential queuing problem. Ultimately, the lower the storage ratio, the lower the probability that queue formation in the interior will jeopardize interchange operational efficiency and safety.

1.2.8 Time-Space Diagram

A time-space diagram (TSD) is a scaled pictorial representation of a roadway and the progress of time in relation to signal timing cycles. It is usually presented in the form of an X-Y graph, where distance along the roadway is the X-axis (in scaled, consistent units) and time is the Y-axis (in scaled, consistent units). TSDs give the analyst the "big picture" of traffic operations and signal timing at each intersection along a given roadway, which in the case of diamond interchanges is the frontage road that joins successive interchanges. An idealized TSD is shown in Figure 12 for frontage road signal coordination. The slope of each line represents the speed of travel necessary to achieve the green bandwidth (i.e., cycle time devoted to progression) shown.
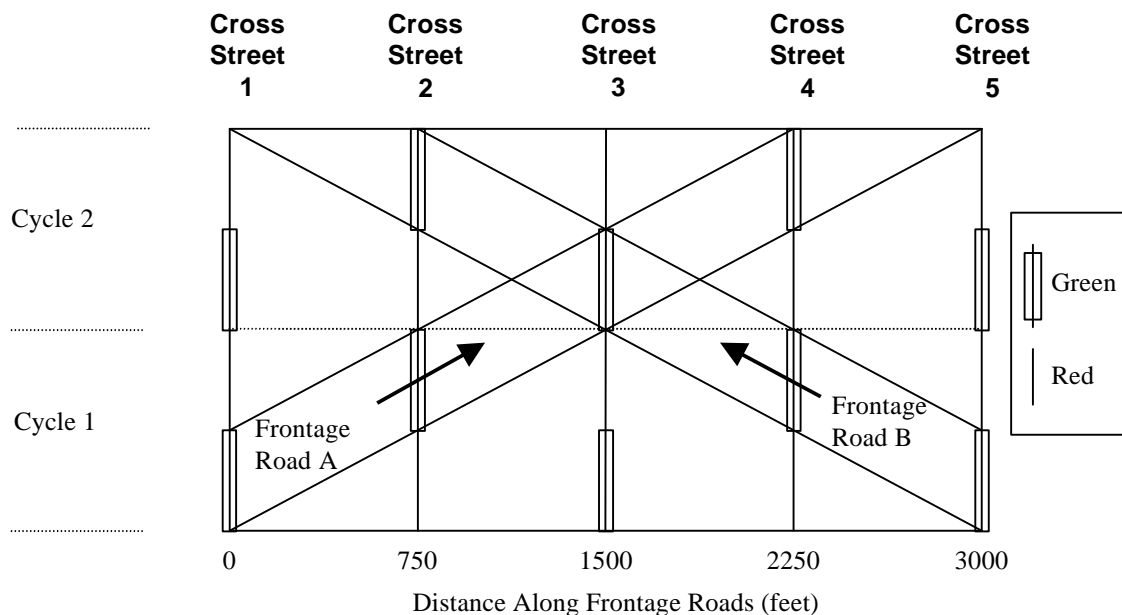
Figure 12. Time Space Diagram for Frontage Road Operations

<u>1.2.9   Driver Expectancy and Other Issues</u>

When developing diamond interchange timing plans, it is essential to consider the environment in which the interchange is located. If you are developing a new timing plan for an interchange that is located along a freeway and all other interchanges along that freeway are operating using a TTI-four phase strategy, driver expectancy develops. Essentially, drivers will expect this interchange to operate similarly to the other interchanges along this freeway (and maybe even in this entire section of the city, if most interchanges operate in a TTI four-phase mode). In this instance, there is the expectation that vehicles departing the arterial approach to go through to the other side of the interchange will receive a green through and left-turn arrow when they reach the other intersection. Also, motorists turning left from the frontage road on green (with the exception of some u-turning vehicles) expect to be able to travel through the interchange without stopping again.

Where the controllers at two or more separate intersections are coordinated for traffic progression, coordination may get out of step, or fall out of synchronization, during cycle-by-cycle resynchronization, during a transition from one timing plan to another, during some pedestrian service calls, and during preemption. As the controllers attempt to regain coordination, shorter or longer phase times may be displayed for some phases, causing driver expectancy issues. This type of driver expectancy is mainly an issue for closely spaced intersections where signal heads may have visibility issues and drivers "expect" a certain operation/timing. This effect is intensified (and some additional controller limitations may impact operations) when the dual controllers managing the diamond are coordinated with other intersection and/or interchange controllers. All transition and coordination impacts must be thoroughly investigated by the traffic engineer developing the plan.

If the features of the timing plan that is to be implemented are significantly different than other interchanges in the area of the study interchange, serious thought should be given to all driver expectancy issues. It is significant to note that the closer the interchange spacing, the greater the driver expectation of green in the interchange interior. If driver expectation issues cannot be avoided, temporary signing should be displayed to indicate that signal operation at the interchange has been altered. As with all signal timing plan development issues, examination of driver expectation issues and (if necessary) countermeasures must be studied in depth, approved and implemented by licensed civil (traffic) engineers and their staff.

A variety of other influences or specialized treatments may impact signalized operations. The prevalence of signal preemption devices or other "ITS" technologies may require special consideration.   Specialized traffic engineers, who understand the specific standards and guidelines required for installation, install many of these special configurations for dealing with these circumstances. These circumstances include railroad preemption if the interchange is adjacent to a railroad grade crossing, fire and/or emergency medical service (EMS) priority treatment, and bus transit and/or rail transit priority treatments. ITS technology is less prevalent and also requires special modifications to standard timing procedures developed within this guide.

2.0   DATA COLLECTION AND ORGANIZATION

Remember the maxim for analytical procedures: "Garbage in, garbage out." It is essential to the integrity of any analysis that the input data is up-to-date, accurate, and representative of general conditions. This is doubly the case with traffic engineering information in that signal timing, a primary output of the process, has a direct bearing on safety and efficiency for the motoring public.

2.1   Traffic Volume Information

A turning movement count (TMC) is required prior to developing an interchange signal timing plan. TMC data is often supplemented by average daily traffic (ADT) counts, which are 24-hour traffic counts of the interchange approach roadways. ADT counts may cover a single direction or both directions along a given roadway, and usually cover all traffic lanes in a given direction. ADT counts can be used to calibrate TMC for off-peak periods. These estimates may need to be reviewed to ensure adequate time for the side street.

2.1.1   Turning Movement Counts

TMC data is collected using a variety of techniques. The most common method is to dispatch a technician to visit the site and conduct the count while in the field. A variation on this method would be to have the technician videotape the intersections (including portions of each approach roadway) on each side of the interchange, return to the office with the videotape, and perform TMC counts from the video. The video creates a permanent record of interchange operations and can also be used to determine the current signal timing at the interchange.

TMC data is most useful for peak periods of the day, with data collected in two-hour blocks that bracket the peak hour. For instance, a common PM peak hour would occur from 5:00 PM to 6:00 PM, so a good data collection bracket would be between 4:30 PM and 6:30 PM. TMC information (i.e., number of vehicles turning left, through, and right) is often collected using manual or computerized counters in 15 minute increments. Each fifteen-minute block of data is transferred from the counting device to a written sheet or computer. Data for all interchange approaches should be collected simultaneously to ensure data integrity, so it is often necessary to have more than one technician at the interchange at one time. It is also necessary to begin the data collection before queues have built up at the intersection. This precaution is necessary to ensure that true demand is counted, not just the number of vehicles that can be processed by the intersection's capacity. In over-saturation conditions, true demand may have to be estimated considering not just the number of vehicles able to make it through the intersection, but also on arrival rates and queue lengths along each approach.

Once the data has been assembled from each approach for the entire interchange, a calculation is made (from all approaches) to determine the fifteen-minute periods with the highest volume. Table 2 contains sample data from a four-leg intersection, with an intersection total volume in the right column. The peak hour is determined from the highest four **consecutive** fifteen-minute periods. In Table 2, the highest (peak) hour is from 4:45 to 5:45 PM. Data sheets may contain

more data than is shown in the example table; the example shows the minimum amount of data necessary to determine the peak period and perform an analysis. An example of more detailed information would be a separate count for automobiles and trucks (heavy vehicles).

Table 2. Sample Turning Movement Count Data

Time (PM)	Northbound			Southbound			Eastbound			Westbound			Total
	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	
4:30-4:45	10	35	10	10	35	10	10	35	10	10	35	10	220
4:45-5:00	**15**	**40**	**15**	**15**	**40**	**15**	**15**	**40**	**15**	**15**	**40**	**15**	**280**
5:00-5:15	**20**	**45**	**25**	**20**	**45**	**25**	**20**	**45**	**25**	**20**	**45**	**25**	**360**
5:15-5:30	**20**	**50**	**25**	**20**	**50**	**25**	**20**	**50**	**25**	**20**	**50**	**25**	**380**
5:30-5:45	**20**	**55**	**25**	**20**	**55**	**25**	**20**	**55**	**25**	**20**	**55**	**25**	**400**
5:45-6:00	10	40	15	10	40	15	10	40	15	10	40	15	260
6:00-6:15	5	20	5	5	20	5	5	20	5	5	20	5	120
6:15-6:30	25	30	5	25	30	5	25	30	5	25	30	5	240
Peak Hour Total (4:45-5:45)	**75**	**190**	**90**	**75**	**190**	**90**	**75**	**190**	**90**	**75**	**190**	**90**	**1420**

An important item to consider when performing your analysis is how volumes peak within the day and within the peak hour itself. Notice that the total intersection volume between 5:30 and 5:45 PM is 400 vehicles. However, the volume between 4:45 and 5:00 PM is only 280 vehicles. Both values are within the peak hour, but there is a sizeable difference between them. The average 15 minute volume is (280+360+380+400)/4 = 355 vehicles per 15 minutes. An indicator known as the peak hour factor (**PHF**) is computed as the peak hour counted volume divided by four times the highest 15-minute volume. Thus, (1420)/(400 X 4) = 0.8875. This is used to ensure that traffic demand does not exceed capacity (as defined by the Highway Capacity Manual) during a 15-minute interval. On facilities near capacity, the peak hour factor will approach 1.0 as the demand spreads out over the peak hour.

Remember that the peak hour factor (PHF) is a measure of volume variability within the peak hour. When the PHF is less than 0.85, you should account for volume variations within the peak period when you are computing your signal timings. A high peak hour factor means special consideration should be taken after the peak is over (i.e., for the non-peak period). Also, actuated operation can be used to accommodate moderately to highly variable traffic volumes.

One additional issue that should be addressed is the measurement of traffic demand rather than vehicle throughput. If an interchange is oversaturated, turning movement counts will not capture the traffic demand that exists. Special consideration should be made to consider vehicle queue counting or other demand estimation techniques when oversaturation is prevalent at an interchange or any other facility.

2.1.2   Average Daily Traffic

ADT information is a valuable resource for checking the accuracy of peak hour TMC counts, checking for the location of the peak hour for each interchange/intersection approach, and monitoring increases in overall traffic volume over time.   Figure 13 shows a hypothetical intersection and one-way ADT counts for each intersection approach roadway.

Time	NB ADT	SB ADT	EB ADT	WB ADT
12-1am	0	0	0	0
1-2	0	0	0	0
2-3	0	0	0	0
3-4	0	0	0	0
4-5	0	0	0	0
5-6	50	50	50	50
6-7	100	100	100	100
7-8	200	200	200	200
8-9	200	200	200	200
9-10	100	100	100	100
10-11	50	50	50	50
11-12	50	50	50	50
12-1pm	100	100	100	100
1-2	50	50	50	50
2-3	50	50	50	50
3-4	100	100	100	100
4-5	200	200	200	200
5-6	**350**	**350**	**350**	**350**
6-7	200	200	200	200
7-8	50	50	50	50
8-9	50	50	50	50
9-10	50	50	50	50
10-11	0	0	0	0
11-12	0	0	0	0
TOTAL	1950	1950	1950	1950

Figure 13. Directional ADT Sample Data

Examination of the ADT values in Figure 13 confirms that the 350 vehicles counted from each direction are roughly the same as the TMC numbers shown (in Table 2) for about that same time period (5 to 6 PM). This check ensures that neither the TMC values nor the ADT values are out of scale with representative values. The high count for the hour from 5 to 6 PM also shows that the ADT numbers indicate what we already discovered - that the PM peak is somewhere around the 5 to 6 PM range. It turns out from the TMC that the actual peak is from 4:45 to 5:45 PM.

Another valuable use for ADT values is to examine the rate of traffic growth over time. If we had counted ADT from the northbound (NB) direction in our example once every year between 1993 and 1997, we would have five data points for checking growth rates over time. Table 3 shows hypothetical traffic counts over this time period.

As seen in Table 3, the volumes constantly increase (though at different rates and volumes) over time. Between 1993 and 1994, volumes increased 5.9%; however, between 1996 and 1997, volumes increased only 2.6%. It is reasonable to calculate an average annual growth rate, which in this case is (5.9+2.8+2.7+2.6)/4 = 3.5%. Thus, ADT history has given us a good estimate of how much ADT is likely to increase in the next couple of years.

Table 3. Growth Rate Calculation

Year	NB ADT	% increase over previous year
1993	1700	-
1994	1800	5.9 %
1995	1850	2.8 %
1996	1900	2.7 %
1997	1950	2.6 %

A useful equation for computing compounded growth rates (i.e., those that grow and build upon each other from year to year) and future volumes is:

$$\text{Future Volume} = \text{Present Volume} \times (1.00 + r)^n \tag{6}$$

where: $r =$ annual growth rate (i.e., 5% is expressed as 0.05)
$n =$ number of years for the traffic projection

This equation should only be used when historical traffic volumes have shown a consistent, compounding increase over time (i.e., an exponential increase).

It is important to note that a traffic count (TMC or ADT) is never an exact count. Not only are errors often made in counting and recording, but traffic volumes themselves are never consistent from day-to-day, week-to-week, or month-to-month. For instance, even in an area where traffic is not growing, a count performed in February will be much different than a count performed in July. Fortunately, state departments of transportation (DOT) usually keep historical records of traffic volumes and month-to-month average ADT variations in an annually published record. This record can be used to "calibrate" your recent count information to account for month-to-month variations in traffic count.

For instance, the state DOT records may show that counts in your area tend to be 1.15 times higher in July than in February, and July tends to be the busiest month of the year. To cover all cases (i.e., use the maximum reasonable traffic volumes in your signal timing analysis), you would multiply your TMC and ADT counts collected in February by 1.15 to produce a reasonable estimate of the highest volumes expected throughout the year. Since signal timings are usually changed only once every few years, it is important to account for month-to-month variations in your analysis. If you used only your February values in your analysis and computed signal timings from those volumes alone, there may be unnecessary delay at your intersection in July because the signal settings could not accommodate the higher volumes.

Remember to use your knowledge of how frequently your signal timings will be updated to frame your analysis. If timings are changed infrequently, you should consider applying factors for monthly variation to volumes used in your analysis. Use maximum likely peak hour volumes to compute peak hour timing. If volumes in your area are increasing rapidly, it will be necessary to update your count data and signal timing more regularly.

2.2   Roadway Geometric Information

A complete understanding of roadway features is as critical as accurate traffic volumes in the development of a signal timing plan. Factors ranging from mixed use lanes (lanes where through and turning traffic are both present) to driveway spacing from the intersection have an impact on how efficiently a lane, approach, or interchange can process vehicles. The most appropriate way for the signal analyst to determine the presence and extent of these factors is by visiting the site and taking the time to observe the operation of the interchange/intersection. All significant roadway and interchange details should be noted, including (but not limited to) the common items listed below. Some elements are depicted in Figure 14.

- Lane use by lane for all approaches and departures;
- Lane widths by lane for all approaches;
- Roadway names;
- Number of lanes for each approach and departure;
- Type of approach lane striping for all approaches;
- Lengths of turn bays along each approach and departure;
- Turning radii within the interchange (field approximation);
- Presence and location of stop bars;
- Presence, location, and size of protective islands;
- Presence, location, and type of signal heads and pedestrian push buttons;
- Presence and location of pedestrian crosswalks;
- Pedestrian walking distances (see section 1.2.5);
- North arrow;
- Adjacent land use;
- Presence and location of roadside angled or parallel parking;
- Distance to nearest driveway upstream from the interchange on each approach and departure; and
- Spacing between intersections in the interchange, measured from the stop bar of the upstream intersection to the stop bar of the downstream intersection along the arterial roadway.
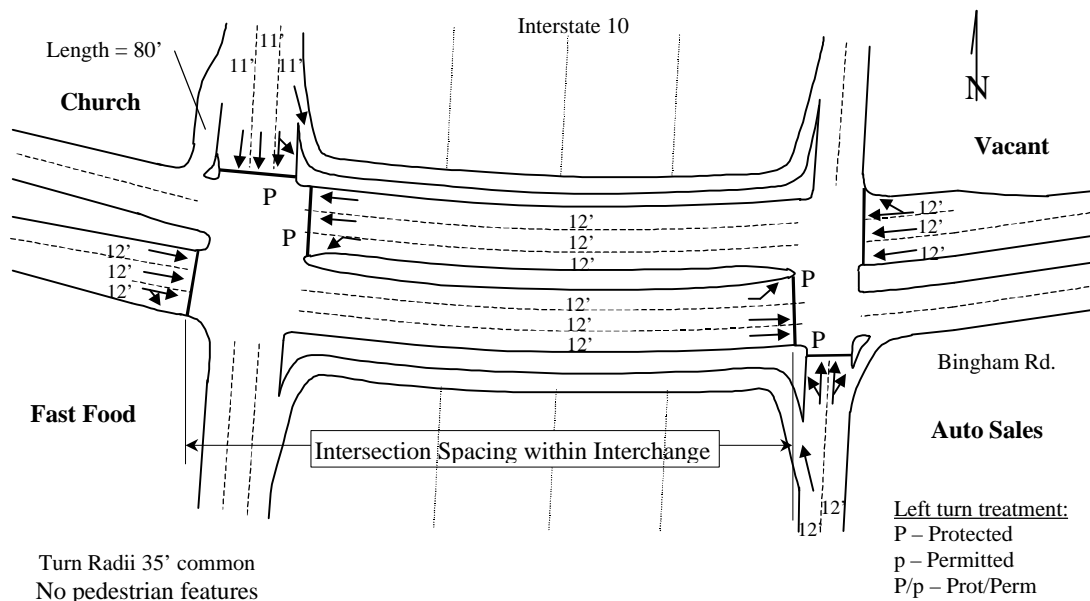

Figure 14. Geometric Details for Data Collection

An additional consideration in examining diamond interchange geometry is thorough documentation of interior geometry and how the interior is "fed" by the arterial approaches to the interchange. The interchange's ability to process left turns is influenced as much by the arterial approach geometry and left-turn storage space as it is by the lane assignment and storage space in the interior. Figure 15 illustrates important points to consider.
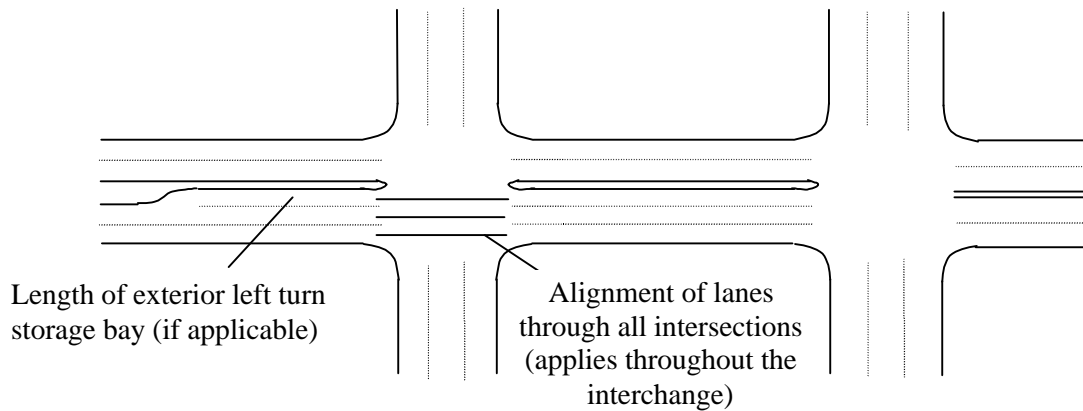

Length of exterior left turn storage bay (if applicable)

Alignment of lanes through all intersections (applies throughout the interchange)

Figure 15. Arterial Approach Considerations for Data Collection

2.3   Signal Timing Information

Several important details about an interchange's signal timing are essential for analyzing existing conditions. An engineer must also consider the capabilities and features of the control hardware in the field prior to strategy development. Other details about the interchange include the type of infrastructure at the interchange, which includes: signal heads, controller cabinets, and other devices.

2.3.1   Left Turn Treatment

The presence of a designated left turn bay within the interior of the interchange allows special consideration to be given to this movement. Observation of the interchange in the field will reveal its current mode of operation.

The left-turn bay may be controlled with either a three- or five-section signal head. A separate three-section head limits the type of phasing to either protected or permitted only. A five-section signal head display will allow a protected/permitted left-turn which can be used to increase the performance and flexibility of the approach. Field observation of left turn operations will verify the type of operation. If no separate indication for left turn vehicles exists (i.e., the only signal heads for each approach are the two, three-section heads called for by the MUTCD (*1*)), permitted operations are virtually always present unless signing indicates that there is a protected turn on green (i.e., no conflicting vehicles are present, as in "split phase" operation). If a left turn treatment of a particular type is desired and the hardware and/or geometry are not capable of accommodating the required display, either the timing strategy will have to be changed or new hardware or geometry will have to be installed in the field.

2.3.2   Mode of Operation and Timing Details

Current practice for signalized intersection timing calls for the use of one of three methods: pretimed, semi-actuated, or fully actuated control. The type of controller affects the type of timing plan that can be implemented. The timing strategies that may be applied are a function of the type and capability of the controller and the operational requirements of the intersection (*8*). Most new controllers are actuated controllers that can execute any of these types of control.

Basic pretimed, also known as fixed time, strategies can be used when traffic at the intersection is relatively steady day to day. These plans utilize a fixed cycle length, phase sequence, and phase lengths to serve traffic. Different timing plans may be programmed to deal with fluctuations in traffic volume throughout the day and to implement patterns that will serve traffic demands. A consistent cycle length and a continuous repetition of the same sequence of signal indications characterizes pretimed operation. The cycle times and phase splits are easily measured and recorded using a stopwatch. If an interchange is currently operating in pretimed mode, it may not have vehicle detectors that are required for actuated operation. Pretimed solutions are effective where volumes follow repeatable patterns.

Actuated control is used at locations where traffic is less predictable and where demand can vary significantly. Actuated control utilizes input from detectors and logic within the controller to adjust green times to serve demand inputs. The standard eight-phase controller with an actuated control strategy allows the use of phases in any sequence provided opposing movements are separated. The signal controller can also omit phases if detectors indicate no demand for a particular movement. This capability can benefit the competing movements and the entire intersection by reducing the time required servicing the movements with demand. The main advantage of actuated control is that the cycle length is allowed to vary to meet traffic demands. Reduced cycle lengths are desirable attributes for isolated interchange control (*9*).

Fully-actuated mode operates without the constraint of a fixed cycle and can only be implemented within a single controller. Phase start and duration are determined by the presence of vehicles over loop detector sensors in the pavement. Internal controller logic maintains a background phase pattern, called a ring structure, so conflicting movements are not displayed simultaneously. A phase is initiated by the detection of a vehicle over the approach sensor. This initial detection provides a minimum green for the movement. As the detector continues to collect demand, vehicles activate the detector and "calls" are placed to increase the green time, or phase time, by a given amount of time, known as the "passage time." This process is continued until there is a sufficient gap in the demand to warrant ending the phase, or the maximum green time is reached. At this time, this phase will terminate (through yellow change and the all red clearance) if there are vehicles waiting on conflicting approaches. If there are no vehicles waiting on conflicting phases, this phase will remain green up until the time that a vehicle does pass over a detector on a conflicting phase. This type of a system is heavily dependent on the detectors for operation. If detectors fail, it will be necessary to adjust the controller to always cause a phase to display (i.e., be set to "recall") for at least the minimum time for each phase experiencing detection failure.

2.4   Speed and Travel Time Information

Many traffic analysis software programs and procedures that apply to multiple signalized intersections and/or interchanges require information not only about the length and features of roadways that join the intersections/interchange, but also about the speed of travel between the signalized junctions. In the case of PASSER^{TM} III-98, it is only necessary to collect speed data between interchanges when you are trying to coordinate the frontage road operations of two or more relatively closely spaced interchanges. Note that the speed information collected should be based only on driving that occurs at a driver's average chosen speed in traffic (i.e., it should not include delay at signals).

The simplest technique for collecting speed data along the frontage roads is to simply select vehicles in the traffic stream at the site and, using a stopwatch, time how long it takes each vehicle to travel from stop bar to stop bar at successive interchanges. Combining this time information with knowledge of the distance between the interchanges allows you to easily compute the speed between interchanges. Of course, this requires that line of sight exists from a safe vantage point to the same-direction frontage stop bars at both interchanges.

The average speed between interchanges can also be obtained using the floating car technique, though this requires much more data collection planning than the observation method. The floating car study is based on the average speed found to exist between two points by traveling within or following platoons of vehicles. The average speed is estimated from five to ten trial runs during off-peak traffic volume conditions and five to ten trial runs during each peak period condition. The speeds obtained should be free flowing speeds of platoons between stop bars at successive interchanges. Trial runs during both off-peak and peak periods should be made to determine if different average speeds occur. Floating car speed studies are safely performed having two persons in the study vehicle; one person to concentrate on the driving, and the other person to record travel time information.

Usable speed information can also be obtained from a speed study performed in the middle of the block between the study interchanges. A variety of devices can be used to collect such data, including radar guns, traffic counting devices, and microwave traffic detectors. If no other information is available or can be collected about the average speed between interchanges, the posted speed limit should be recorded and used in analyses.

Not only is speed data required along frontage roads (i.e., between interchanges), it is also required between the two intersections that make up the interchange. This speed data element is considered if you select to use the PASSER III^{TM}-98 simulation module, TexSIM, to simulate the operation of a single interchange whose operation has been analyzed. The best methods for collecting travel time information between the stop bars of the two interchange intersections are the observation/stopwatch technique and the floating car technique.

The final speed elements that pertain to interchanges are the speeds (and travel times) between arterial intersections and the diamond interchange that are needed for diamond-arterial coordination. However, as this is beyond the scope of the PASSER^{TM} III-98 software, it will not be discussed here.

3.0   PASSER^{TM} III-98

PASSER^{TM} III (Progression Analysis and Signal System Evaluation Routine) was originally developed by the Texas Transportation Institute (TTI) for TxDOT. First available in the mid-1980's, PASSER^{TM} III is the only publicly available microcomputer software capable of optimizing the operation of signalized diamond interchanges. PASSER^{TM} III-98 for Windows 95/98, the current version, is a macroscopic analysis tool that uses the delay difference of offset method to optimize traffic flow through the two signalized junctions of diamond interchanges. It is especially powerful as an optimization tool when used with the microscopic intersection simulation tool developed by TTI and provided with the PASSER^{TM} III-98 software. Optimized settings output by PASSER^{TM} III-98 can be simulated using the animation module. The analyst can observe queuing behavior and general performance, making fine-tuning adjustments throughout the process. A maximum of 15 interchanges can be analyzed at one time.

3.1   Installation

3.1.1   Installing the PASSER^{TM} III-98 Software

The installation routine for the PASSER^{TM} III-98 software is automatically loaded when you install the PASSER^{TM} III-98 CD into your CD-ROM drive. In essence, the "Autorun.exe" file on the CD is executed upon insertion. You are presented with a PASSER^{TM} III-98 windows tile (see below), or "launchpad," from which you can choose to run the PASSER^{TM} III-98 program off of the CD, install the program onto your computer's hard drive, install/use a Microsoft Word viewer for viewing PASSER^{TM} III-98 input and output files, or "close" the CD.

Figure 16. PASSER^{TM} III-98 Launchpad

If the launchpad does not automatically activate when you insert your PASSER^{TM} III-98 CD, you can search your CD drive until you find the "Autorun.exe" executable file and double-click it. Like many Windows 95/98 compatible programs, PASSER^{TM} III-98 uses a common installation interface. For the most part, installation is automatic and requires little or no input from the user. On completion of the installation, the PASSER^{TM} III-98 program and its components are loaded on the computer's hard drive (i.e., C: or D:) under the "P2000" directory. PASSER^{TM} III-98 adds a "PASSER 2000" icon to the Windows 95/98 desktop that will provide

the most easily recognizable link to the program. An icon is also added to the Windows 95/98 "Programs" folder that can be reached by mouse-clicking to "Start|Programs|PASSER 2000." Within the PASSER 2000 heading are icons for help using PASSER^{TM} III-98, the PASSER^{TM} III-98 program itself, a traffic animation module, and help for using the animation module.

3.1.2 Uninstalling the PASSER^{TM} III-98 Software

If you decide to uninstall the software, removal from the hard drive is facilitated by using the Windows 95/98 program removal utility found under "Start|Settings|Control Panel|Add/Remove Programs." Simply selecting the PASSER^{TM} III-98 entry and clicking "Add/Remove" will uninstall the program files from the computer. Depending on what other software is loaded on your computer, you may be prompted as to whether or not you want to delete a shared ".dll" file. In this instance, it is almost always best to respond "No," thus leaving the ".dll" file to be used by other programs. Instances of shared ".dlls" with PASSER^{TM} III-98 are rare, but correct action ensures that other programs will not be affected by the PASSER^{TM} III-98 uninstall.

After the uninstall, any input or output data files will remain on the computer's hard drive. An intilization file, "P2000.ini," will also remain on the computer in the Windows folder. If PASSER^{TM} III-98 is installed on this computer again, the settings (i.e., user defined settings, such as revised saturation flow rate) that accompanied the original installation can be resurrected and used again. Simply deleting the "P2000.ini" before reinstallation will allow the PASSER^{TM} III-98 default values to be used if the software is installed again.

3.1.3 Accessing the PASSER^{TM} III-98 Program

Double clicking on the PASSER^{TM} III-98 desktop icon will initialize the program and create an active PASSER^{TM} III-98 window that looks like the screen in Figure 17. PASSER^{TM} III-98 can also by accessing "Start|Programs|PASSER 2000|PASSER^{TM} III-98."
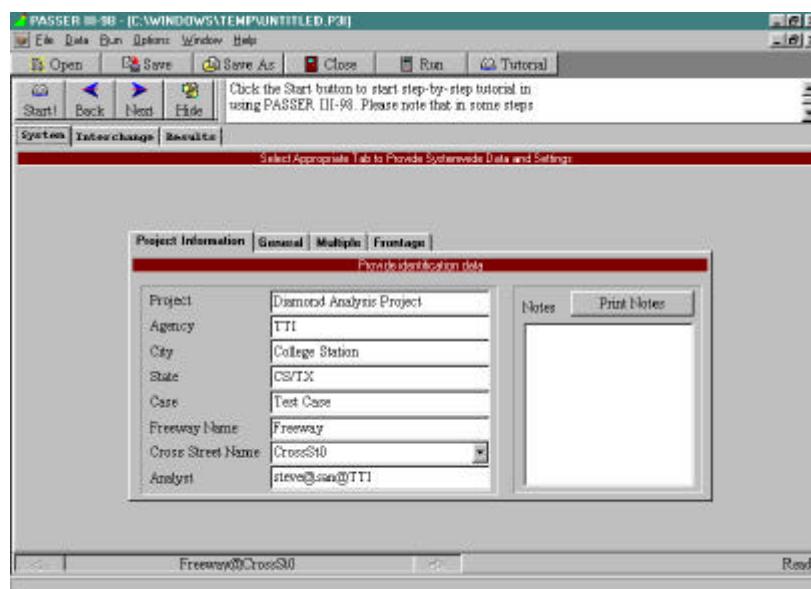

Figure 17. Starting PASSER^{TM} III-98

3.2   PASSER^{TM} III-98 Setup and User Interface

Before we discuss entering data into the program, we will discuss the File menu bar and how it can be used to setup and configure PASSER^{TM} III-98. As with other Windows 95/98 programs, the file menu bar offers you the primary options and functions available from the program.

3.2.1   File Menu Bar

In PASSER^{TM} III-98, you have mouse-click access to **File** utilities, **Data** setup and configuration, **Run**ning the program, setting **Options**, adjusting the active **Window**, and getting **Help**. The file menu bar, like other menus found throughout the program, also allows "hot key" access to each of these functions by pressing the "Alt" key and the underlined letter for each heading item. Under the File menu heading (Figure 18), you have the option of:

- creating a new file;
- opening an existing PASSER^{TM} III-98 file;
- saving the active file and/or saving the active file under a different name;
- closing the active file;
- printing the active data form;
- copying the active form to the Windows 95/98 clipboard;
- editing an existing file;
- exiting the PASSER^{TM} III-98 program; or
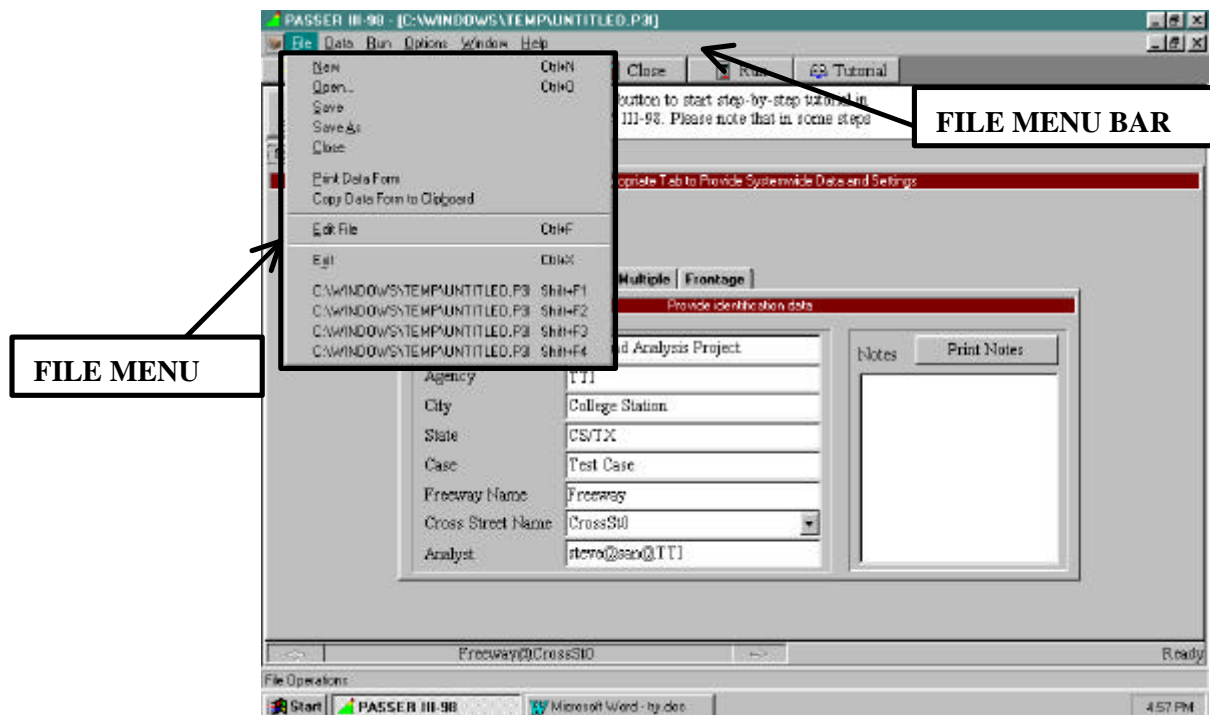- selecting a recently completed data set for further analysis.

Figure 18. File Menu

The Data menu contains selectable items, third level submenus (i.e., the items with arrows off to the right), and general settings for PASSER^{TM} III-98. At the top of the Data menu, three selectable items offer you the option of whether or not you would like PASSER^{TM} III-98 to automatically calculate saturation flow, travel time within your diamond interchange, and the traffic storage volume within your interchange. As you want to ensure that PASSER^{TM} III-98 is always using calibration values that are consistent with your active input file, you will most likely leave these three items checked, or active.

The "QuickFill Values" selection allows you to quickly change the ideal saturation flow rates, grades, minimum phase time, lane width, and truck percent used in your active input file. Note that using QuickFill changes all such values throughout your entire input file and for all interchanges in that input file. The next entry, Set Default Ideal Saturation Flow Rate, allows you to change the default saturation flow rate (i.e., 2000 vphgpl) to a value between 1600 and 2200 vphgpl. Setting this value as the default means that it will be used in all calculations within your active input file and it will be saved as the new default value for future analyses.

The three "Set Parameters" entries allow you to easily enter in default values for automobile and heavy vehicle length; dollar costs for delay, stops and fuel; and thresholds for degree of saturation, control delay, and storage ratio. As with the other "Set" entries, changing the default values impacts the entire input file and uses the changes in future PASSER^{TM} III-98 analyses.

Finally, any settings that you have just modified for the active input file can be saved and used as the default values that appear in all of the data entry windows in PASSER^{TM} III-98 in the future. This feature will likely be of benefit to you if you have to analyze many interchanges of similar nature. It is helpful to have to enter the basic interchange information only once, and then edit it to suit the analysis case at hand. Because the default values can be changed, it is a good idea to always check all of the above entries so that you know which default data and calibration values PASSER^{TM} III-98 is using for any analysis that you perform.
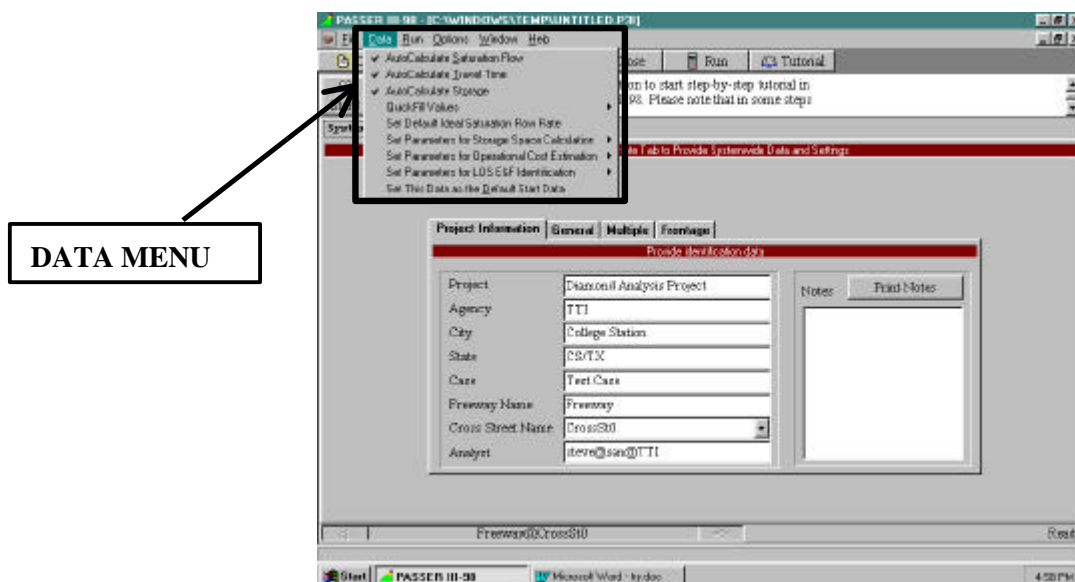

Figure 19. Data Menu

The Options menu allows you to configure the PASSER™ III-98 software environment. The first entry allows you to use metric units rather than the (default) English units. Next, you have the option of enabling PASSER™ III-98 sound files (if you installed them), which play a significant role when using the program's self-contained tutorial. The third item within the Options menu, "Hide Icons and Note Panels," enables you to turn off the file function/icon bar located beneath the file menu bar. Selecting and unselecting the "Show Hints" item allows you to display or not display the blue-background hint windows that appear as you move around the PASSER™ III-98 screen. The "View Status Bar" entry allows you to toggle the status bar at the bottom of the screen on and off. However, this screen is usually left on because the status bar allows you to switch between different interchanges when you are analyzing multiple interchanges at one time.

Whereas the top five Options menu items affect aspects of the PASSER™ III-98 user interface environment, the last two entries affect how PASSER™ III-98 works with other programs and the Windows 95/98 operating system. The "Select RTF and Animation Viewers" entry allows you to select a viewer other that the default Word for Windows (i.e., winword.exe or wordview.exe) for viewing the RTF (rich text format) text used in the PASSER™ III-98 output file reports. It is strongly recommended that the default be used. This entry also allows you to select animation software other than the default (i.e., tex.exe, the TEX traffic simulator developed by TTI). Again, it is recommended that you retain the default animation program. Finally, the "Edit P2000.INI File" entry allows you to save PASSER™ III-98 configuration information you have entered using the Options menu into the PASSER™ III-98 startup on a permanent basis. If you opt to select this entry, PASSER™ III-98 will use the user environment settings you have selected until you make changes and highlight "Edit P2000.INI File" again.
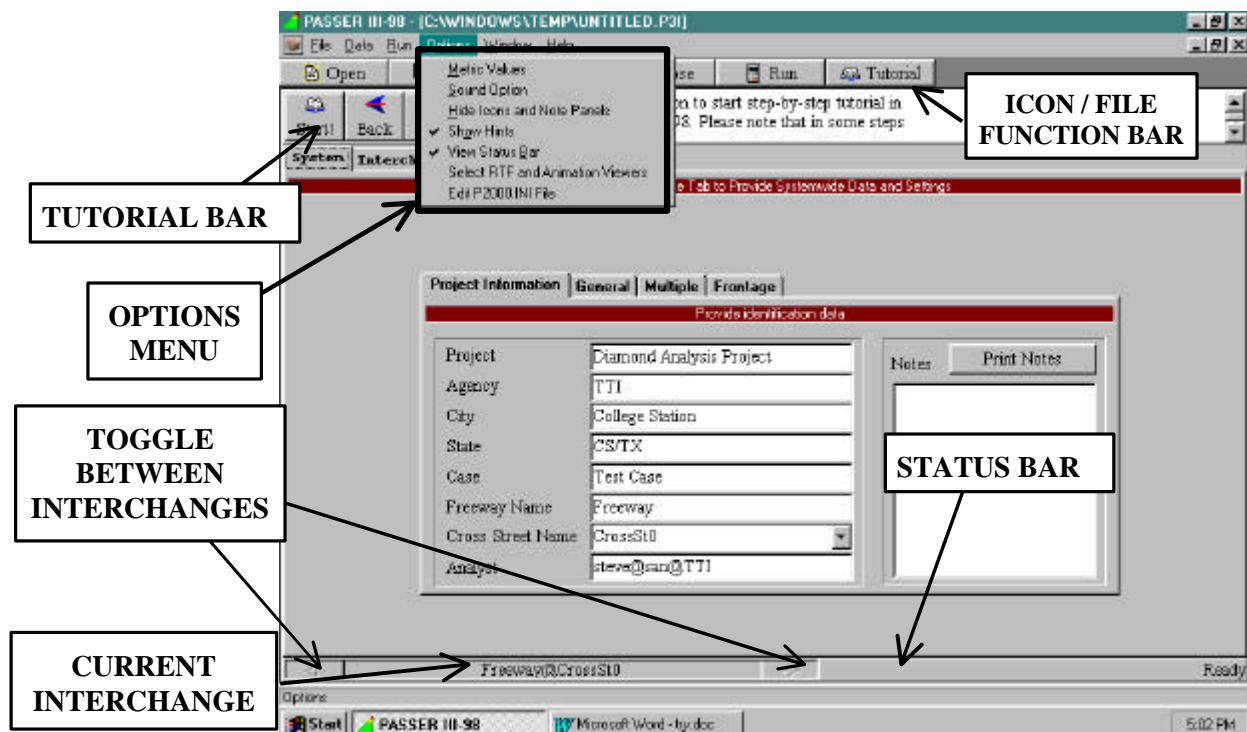

Figure 20. Options Menu

The Window menu gives you flexibility in how you display various windows within the PASSER^{TM} III-98 program. If you are editing data for multiple interchanges, you can tile or cascade the data input windows for each interchange for ease of access. You can also automatically arrange the icons of multiple interchanges whose data windows are minimized.

This menu also allows you to change the graphic background within the PASSER^{TM} III-98 program. A variety of solid color backgrounds are available, and a shaded blue background in available. You can also impose a bitmap over the PASSER^{TM} III-98 background. Several bitmaps (i.e., *.bmp files) for this purpose can be found under C:\P2000\P3. You can also use bitmaps that were shipped with the Windows 95 or 98 operating system. These files can be found under the C:\Windows directory.
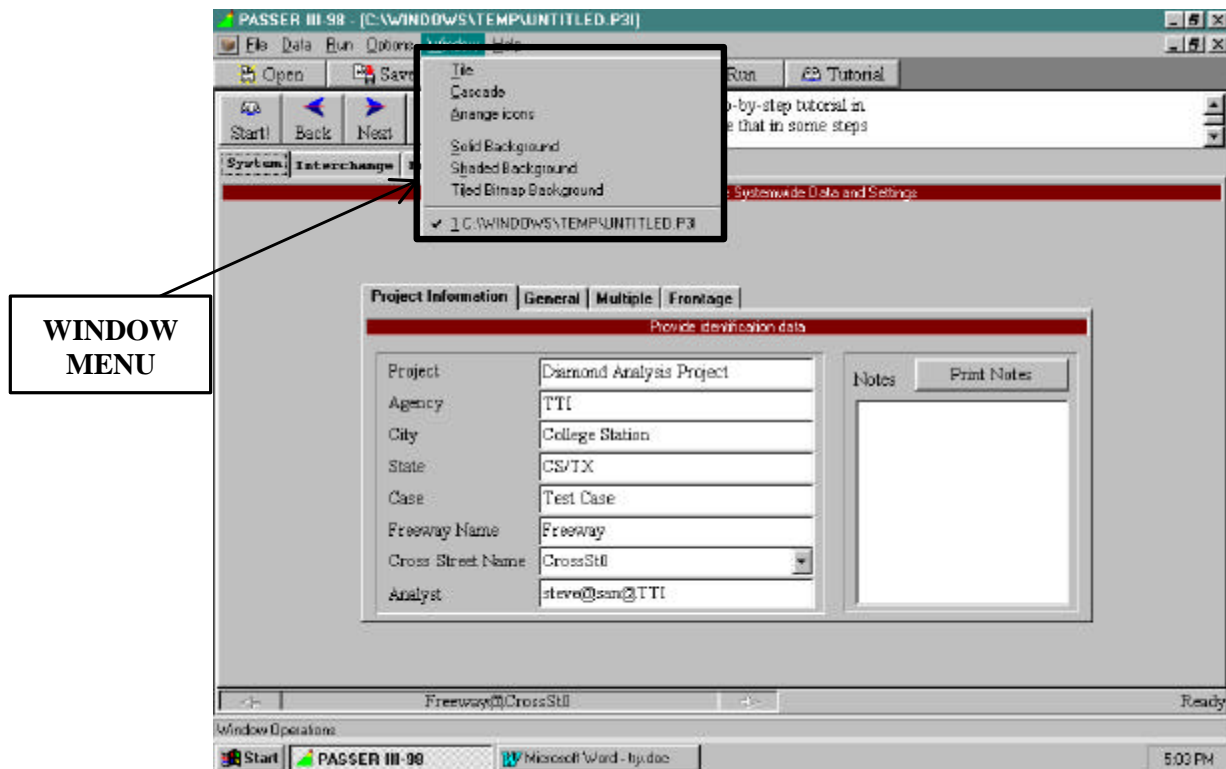

Figure 21. Window Menu

3.2.2 Help Resources

The Help menu provides ease of access to the many types of help available within PASSER^{TM} III-98. This menu also allows you to view legal information about the PASSER^{TM} III-98 program and the PASSER^{TM} trademark. An "About" entry allows you to view the PASSER^{TM} III-98 launchpad. Finally, credits are available that document the many sources of expertise that were drawn on in the development of the original PASSER^{TM} III program and the current, PASSER^{TM} III-98 version.
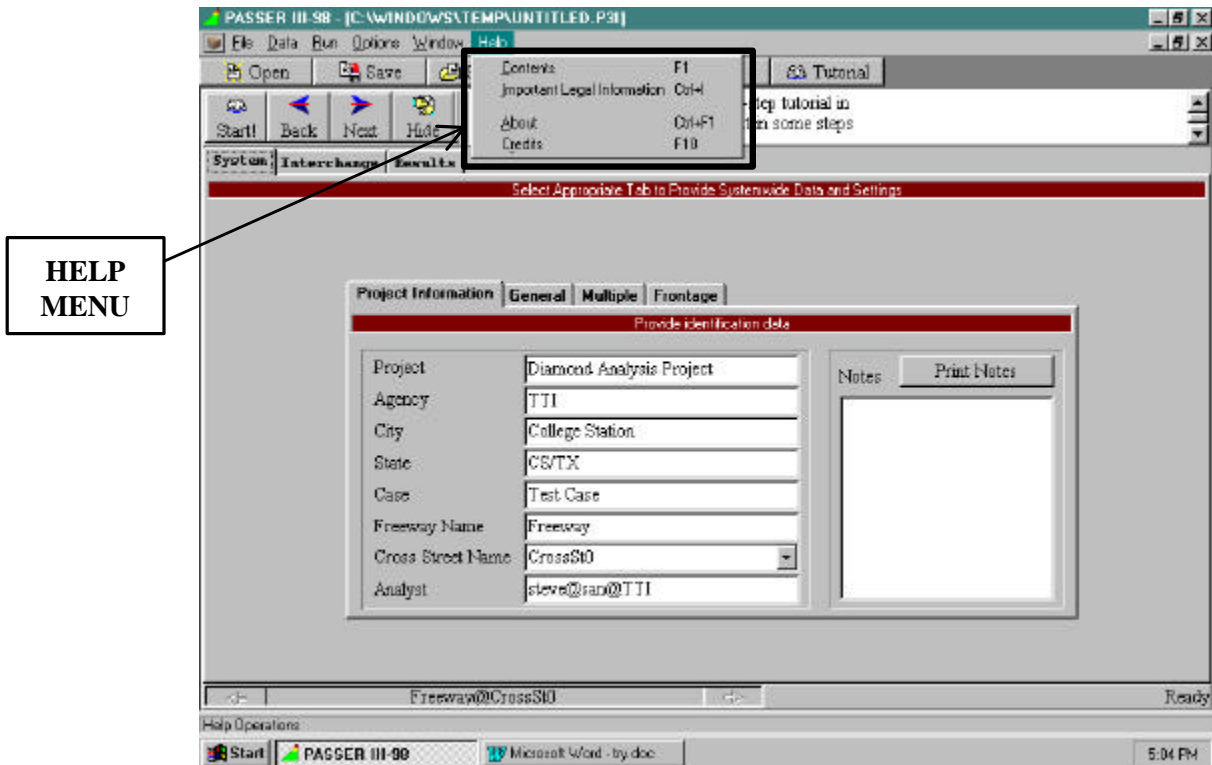
Figure 22. Help Menu

On selecting the "Contents" entry from the help menu, you will be presented with a help window that looks like Figure 23. This window has many of the same features as help files found in other Windows 95/98 programs. For instance, From this window, you can print, copy from, bookmark, and/or annotate the help file or portions thereof. You also have control over how the help window is displayed in the PASSER^{TM} III-98 program window.

A control bar is provided at the top of the help window (but below the help file menu bar) that allows you to view help file contents (i.e., return to the main help file screen), search the help file by keyword, go back to a help file item you have recently left, print a section of the help file, or advance forward or backward in your search. In addition to the control bar, items within the help file can also be reached by mouse clicking the green, underlined words found in the help screen. Topics available include Introduction, Disclaimer, Data Editor, Interface, Output Details, Glossary, and Acknowledgements. Many of these items access the same information that can be reached through either the help menu or the PASSER^{TM} III-98 tutorial, but are included here as comprehensive user documentation within the program.

3.2.3   PASSER^{TM} III-98 Tutorial

A user-paced tutorial is available within PASSER^{TM} III-98. It is located on the screen below the Icon/File Function Bar and contains clickable buttons that Start the tutorial, move back in the tutorial (i.e., "Back"), advance in the tutorial (i.e., "Next"), and "Hide" the tutorial bar. A white background with black text box displays the current tutorial message to the user (Figure 24).
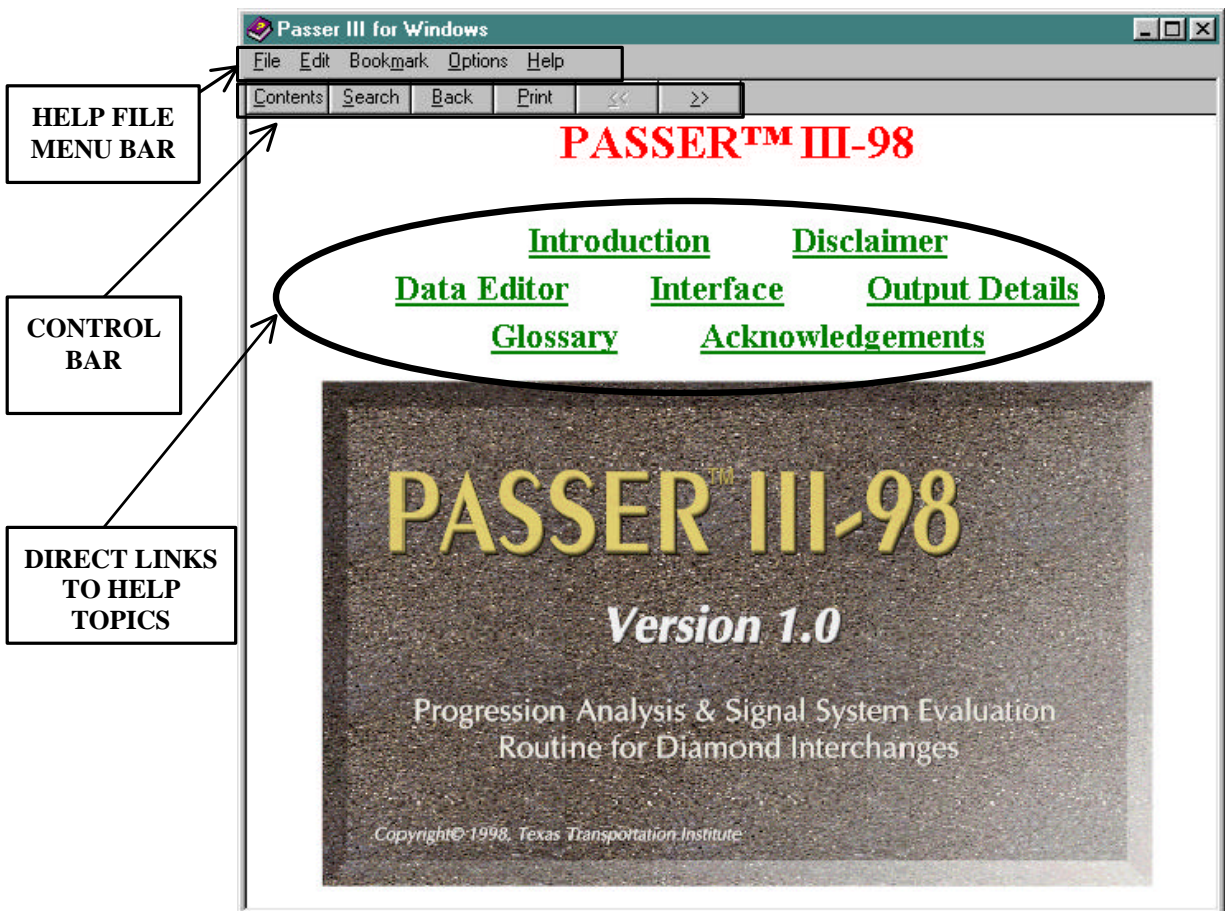
35

Figure 23. Help Utility User Interface

As you progress though the tutorial, you may need to scroll down within this text box in order to read all of the text contained within the box. If you do not see the tutorial bar when you are using PASSER^{TM} III-98, it can be brought up by clicking on the "Tutorial" button on the Icon/File Function Bar. If you installed the sound files for the tutorial when setting up PASSER^{TM} III-98 and you have a sound card and speakers, you can have the text read to you as well. The sound files (i.e., *.wav files) will not automatically install using the PASSER^{TM} III-98 installation utility, but they can be copied off of the CD-ROM onto your hard drive in the same directory (i.e., C:\P2000\P3*.wav) they were found on the CD-ROM. As these files are only used to add an audio feature to the tutorial, they can be deleted after using the tutorial to conserve space on your computer's hard drive.

It is recommended that you use the tutorial the first time that you use the PASSER^{TM} III-98 software. Even users who have experience using the older, DOS-based versions of PASSER^{TM} III will learn new features of the software and learn more about how this latest version works.
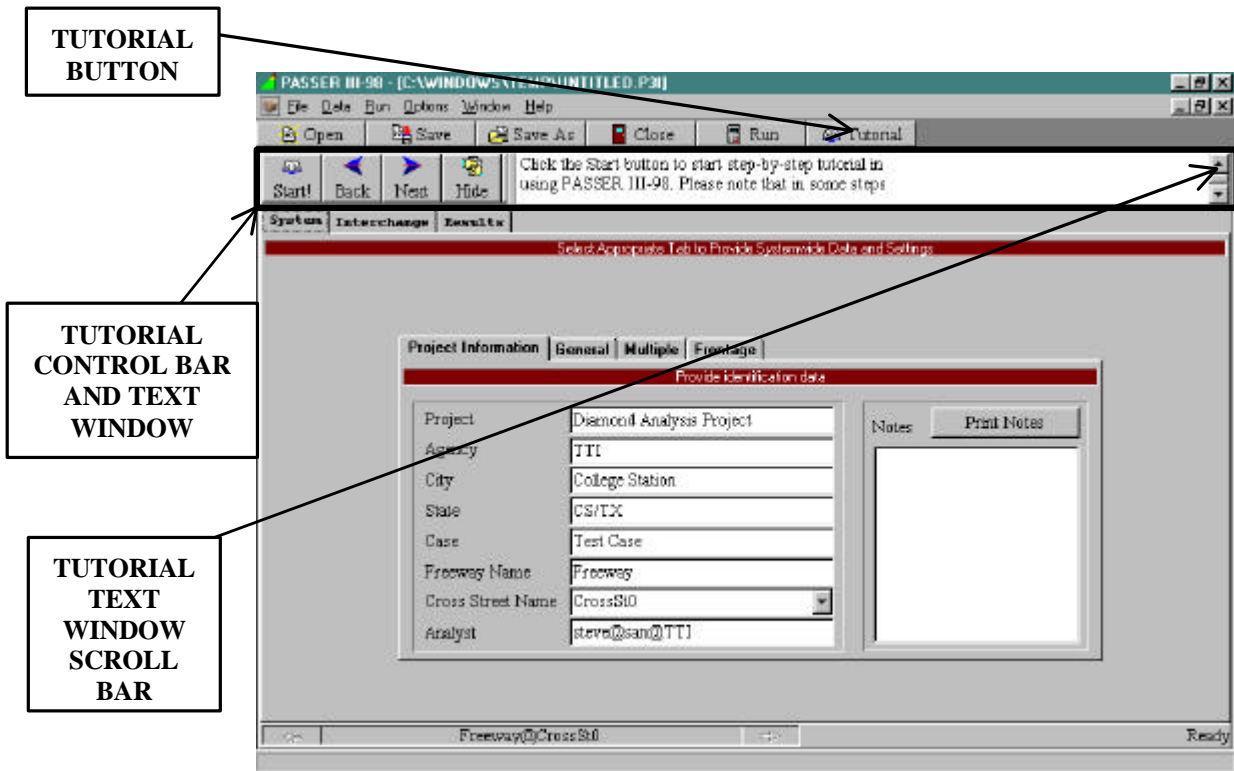
**TUTORIAL
BUTTON**

**TUTORIAL
CONTROL BAR
AND TEXT
WINDOW**

**TUTORIAL
TEXT
WINDOW
SCROLL
BAR**

Figure 24. Tutorial Bar

3.3   Inputting Data into PASSER^{TM} III-98

PASSER^{TM} III-98 data input is organized using a hierarchical structure of folders, referenced by tabs in the user interface. The top levels in this structure are the System, Interchange, and Results folders/tabs found beneath the tutorial control bar. When you first begin PASSER^{TM} III-98, you will see a screen like the one shown in Figure 25. Notice that you are in the System folder, and that you are viewing the Project Information subfolder within the System folder.

With your traffic volume information, roadway geometry data, and signal timing data (if simulating existing signal operations) ready at hand, you are prepared to begin entering the input data required by PASSER^{TM} III-98. The easiest way to manage your data entry and ensure that you have entered in all of the data that PASSER^{TM} III-98 requires is to pace through the subfolders within each main folder (i.e., System, Interchange, and Results) from left to right, entering all data as you proceed. Thus, within each folder, you know which data elements have already been input and you know the quantity and type of data that remains to be entered. After using the software, you will quickly associate the folder and subfolder names with the types of information contained within them.
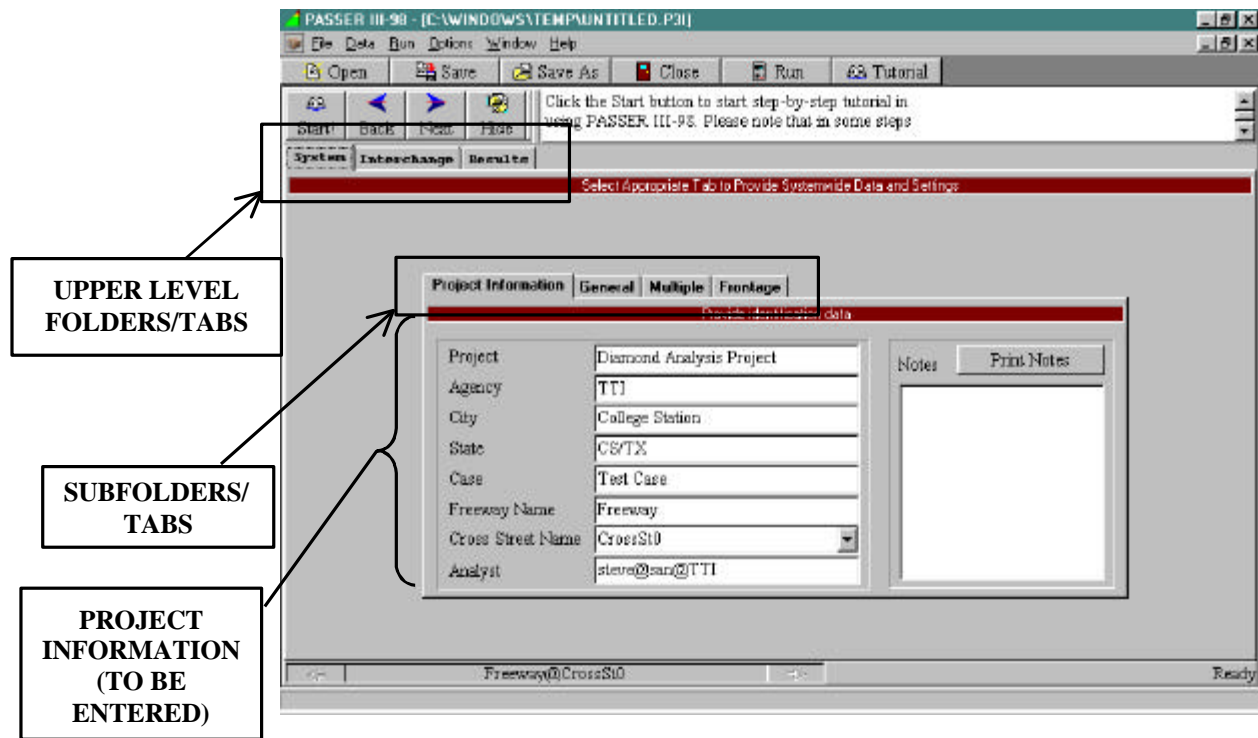
Figure 25. Project Information Data Entry

3.3.1 System Folder

Project Information Subfolder

At the first input screen (i.e., the Project Information subfolder shown in Figure 25), enter in the project name, your agency/organization name, the city and state where your analysis site is located, a name for your analysis case, the name of the freeway, the name of the crossing arterial roadway (i.e., the name of your first interchange in a multiple interchange analysis; you can return to this screen later to type in names for additional interchanges), and your name. Notice that a printable notepad is available that you can use to further identify your analysis case and, possibly, describe features of alternatives that you may be evaluating as part of this analysis.

General Subfolder

The General subfolder (Figure 26) is the next data entry point, as it as to the right of Project Information (and we are proceeding from left to right through the subfolders within each main folder). The first information element to be provided at this screen is the cycle length or cycle length range to be analyzed. If you are simulating existing signal operations at a diamond interchange, you would enter in the same number (the existing cycle length) for both the "From" and "To" portions of this data element, and you would leave the "Increment" entry blank. If optimizing signal operations, you would enter the lower and upper ends of a realistic cycle length range under "From" and "To," respectively. It is usually best to use ranges of no greater than 30 seconds at one time, in order to limit the size of the output file and provide a quantity of output

that is readily comprehensible. The "Increment" entry also plays a large role in the size of the output file, as analyzing a case with a 1-second increment produces ten times the output of a 10-second increment. Five and ten second increments are common in preliminary analyses, with smaller increments used within a tighter cycle length range as a fine-tuned, optimal solution is approached through iterative program runs.
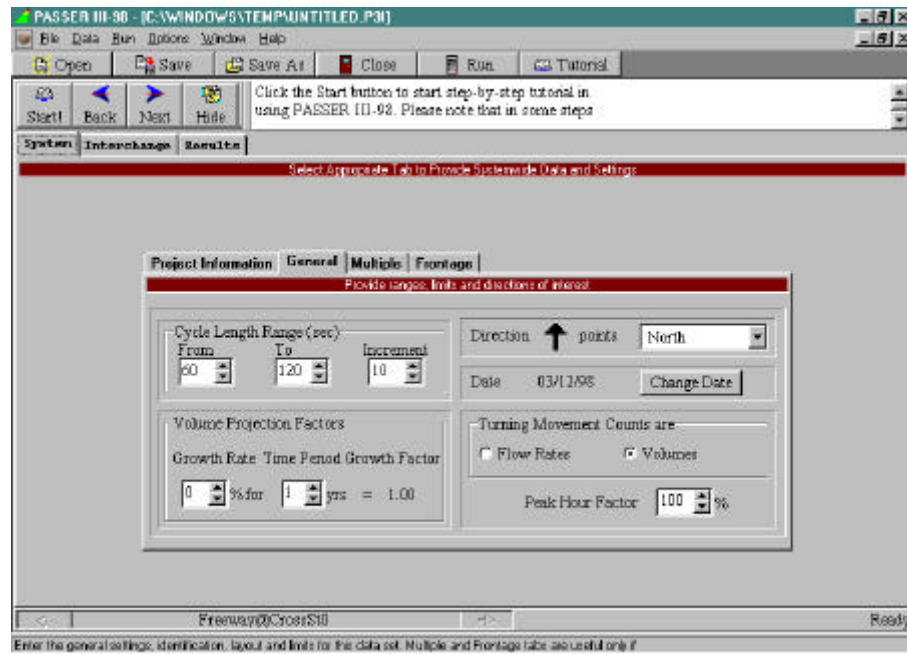

Figure 26. General Subfolder Data Entry

The next data to be entered is growth rate information, if applicable. If you are performing an analysis of existing traffic counts for purposes of developing signal settings, you would leave the growth rate set to "0" percent, and the growth factor would be "1.00." However, if you are performing an analysis requiring future volumes (i.e., improvement alternatives, future timing needs), PASSER^{TM} III-98 will calculate and use a compounding annual growth rate for you. Simply enter in the annual percentage growth rate and the number of years into the future you would like your existing volumes projected. The resulting growth factor, which will be used by PASSER^{TM} III-98 to calculate your analysis volumes, is displayed.

Other information to be entered on this screen includes the cardinal direction within your analysis represented by "up," or the top of your screen. If desired, you can also change the date from the default, which is taken from your computer's clock when a file is created. You must select the format of your input data, be it 15-minute flow rate data or hourly volumes. Finally, you must input a value for peak hour factor if you have chosen to input your data in hourly volumes. If you have already accounted for peaking in the volumes you have on your data sheets, do not enter in a PHF (i.e., leave the 100% default). If you have not accounted for peaking in the numbers you will be entering into PASSER^{TM} III-98, enter in the PHF here.

Multiple Subfolder

The next subfolder you encounter in your data entry is the Multiple subfolder (Figure 27). Within this data entry screen, you will tell PASSER^{TM} III-98 the number and order of a series of interchanges in your freeway/arterial network. If you are analyzing a single interchange, you can check this screen to ensure that no information is specified for multiple interchanges, and then move on to the next data entry subfolder.
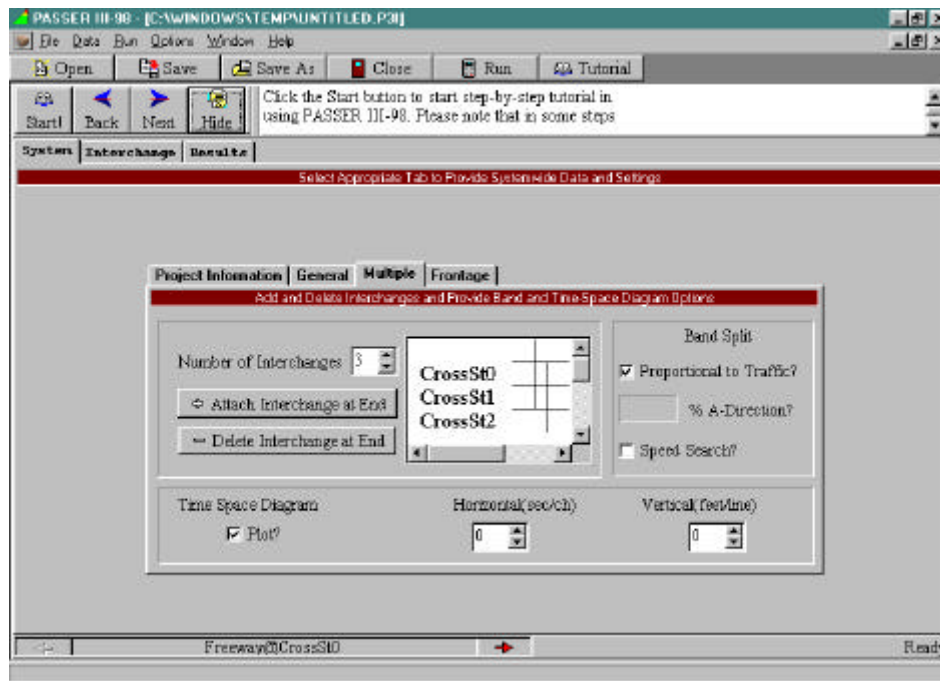

Figure 27. Multiple Subfolder Data Entry

The first data element to be entered here is the number of interchanges in your system. The number of interchanges coded must be between 1 and 15. Click in the box provided and enter the appropriate value, or use the up-down buttons provided by the side of the box. You can also click in the box and then use the up or down arrow on the keyboard.

Next, provide PASSER^{TM} III-98 with some information about how it should attempt to optimize progression along the frontage roads between interchanges. If you would like the program to base its bandwidth calculations on the traffic volumes you will enter, select Band Proportional to Traffic. If this option is checked, the A-Direction Percentage is ignored. If this option is not checked, provide the percentage of priority that needs to be given to the A-Direction (from interchange 1 to interchange N). If a value of 100 is entered, a one-way progression solution will be provided in the "A" direction; if a zero is entered, a one-way progression solution will be provided in the "B" direction (from interchange N to interchange 1). If you would like some flexibility in PASSER^{TM} III-98's use of speed in arriving at an optimal bandwidth solution, check Speed Search. This enables the program to uniformly add or subtract up to 2 mph on each link (i.e., between each interchange pair) to find the maximum system bandwidth.

The remaining data entry on this screen supplies the program with the information it needs to create a time-space diagram output of a bandwidth solution between the interchanges of a multiple interchange system. If you would like PASSER™ III-98 to generate a Time-Space diagram, check this option. Notice that you can now adjust to plot settings for the Time-Space Diagram; plot settings in the time axis of the time-space diagram can be provided in seconds and plot settings in the space axis of the time-space diagram can be provided in feet.

Frontage Subfolder

The data input in the Frontage subfolder (Figure 28) is required only for analyses having multiple interchanges. If this is the case, it is assumed that you desire to coordinate the signal timings of the adjacent signalized diamond interchanges to provide progression for frontage road traffic between the interchanges, as if the one-way frontage roads formed a divided arterial street. Each line of data on this screen pertains to the two links connecting adjacent interchanges. Changes can be made by clicking in the appropriate column and row of the table in this panel.

Figure 28. Frontage Subfolder Data Entry

The Speed input is the desired average running speed in miles per hour for the link described in the first two columns of the table. The Distance entry is the distance from one interchange to the next. Normally, this distance is measured from stopbar to stopbar of the two interchanges.

The Queue Clearance entry is the time required to clear a standing queue before the arrival of a progressed platoon of traffic. The vehicles forming the standing platoon are likely to be vehicles that have turned onto the frontage road from intersecting driveways and/or minor streets. With an adequate queue clearance time given, these vehicles can clear the intersection and the platoon can arrive and pass through the interchange without stopping. In some cases (i.e., when "slack" time is available at an intersection), PASSER™ III-98 may produce a queue clearance time as an

41

output, even if no queue clearance time was input. Therefore, it is recommended that an initial run be made with zero queue clearance times. A second run can be made by giving queue clearance times based on the results of the initial run, or manual adjustments can be made to the time-space diagram.

Progression related information (i.e., speed, distance and queue clearance) data must be entered for links in each frontage road direction (i.e., both From-To and To-From).

3.3.2   Interchange Folder

Approaches Subfolder

When you have completed data entry within the System folder, move on to the Interchange folder. The first subfolder you will encounter is the Approaches subfolder (Figure 29). At this screen, you will provide details that describe the lane presence, features, and usage at each approach to the two intersections that form the interchange. Notice that one of the approach lane groups in the interchange diagram to the right is highlighted in blue. It is the blue lane group that is active, and this is the lane group for which you are entering in data. To move to a different lane group, simply mouse-click the shaded circle closest to the lane group you wish to edit. For an expanded view of the interchange graphic, mouse-click on the "+" located to the left of the interchange diagram. After viewing the expanded graphic, mouse-clicking the "-" will return you to the approach data entry screen.
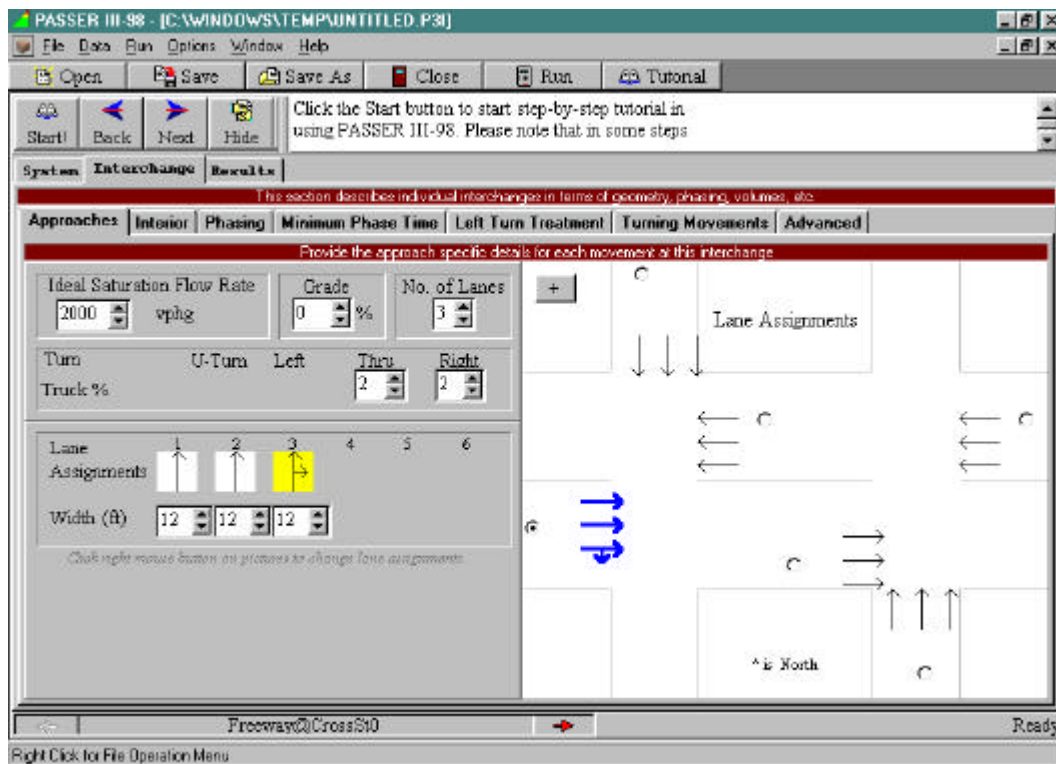

Figure 29. Approach Subfolder Data Entry

The first data element that you can edit is the entry for the ideal saturation flow rate. Editing this value here will create a new value that will be used only for this approach; the default value will remain and appear when you move to the next approach. Keep in mind that the value entered here is an ideal flow maximum – it will be factored down to the actual saturation flow rate based on other information you enter into the program.

The next data elements to be entered are the grade for the approach (uphill is positive; downhill is negative) and the number of lanes on the approach. The number of lanes that you enter should be inclusive of turn bays, if those turn bays are readily accessible (as is normally the case with properly designed bays) and not blocked by the queue. If a right turn bay is separated from the other approach lanes with an island or channel (i.e., the right turn traffic does not actually pass through the signal controlled portion of the intersection), it should not be counted in the lane total and its volume should not be included in the volume total for the approach.

Next, enter in the truck percentage for each movement on the approach. Notice that some movements are blanked out, indicating that those movements do not compose the lane group for which you are currently entering data.

The final data elements to enter for each approach are the lane assignments for each lane in the current (i.e., highlighted) lane group and the widths of each lane in the lane group. Lane assignments are easily changed by positioning the mouse over the lane usage icon and clicking the right mouse button. A check box appears with the eligible movements possible from the lane, and these can be selected/unselected by left-clicking the desired choice. As an example, if your current lane usage is through only and you want to make it through+left, position the mouse over the lane to be changed, right click the mouse, and left click the mouse over the words "Left Turn." Notice that the lane is now a through+left lane. In some cases, PASSER^{TM} III-98 may not allow you to make certain lane use choices. If you encounter this situation, check the lane use in adjacent lanes to make sure that they are not incompatible with your desired choice in the current lane. When you have completed lane use selection, use the up/down arrow boxes to select the appropriate lane width for each lane in the current lane group.

When you have completed data entry for the current lane group, move on to the next lane group around the interchange until you have entered in data for all six lane groups.

Interior Subfolder

Within the Interior subfolder (Figure 30) you enter in geometric and roadway descriptive information about the length of arterial roadway joining the two intersections that form the interchange. This information must be entered for both directions of traffic.

The first data element is the length of the roadway link in the interchange interior. It is commonly measured at an interchange site as the distance along the arterial from the exterior approach stopbar to the interior approach stopbar for the same direction of traffic flow. The next information elements are the number and length of left turn bay lanes for each direction. In this case, bays are considered to be lanes which do not cover the full distance between the two intersections (i.e., the bay length is shorter than the interior link length). If your interchange has

two bays in a given direction, enter the average length of the bays rather than their combined length. The last item of data entry for each direction of traffic is the speed. The observed average speed along the arterial within the interchange is the best value to enter. PASSER^{TM} III-98 will use this speed in calculating a travel time for the vehicles departing the arterial external approach queue and travelling into the interchange interior to make a left turn or go straight.

Figure 30. Interior Subfolder Data Entry

Notice that as you enter data values in this screen, PASSER^{TM} III-98 is automatically computing both a travel time and through and left storage values for each direction of traffic. The travel time being computed is the time required to travel along the arterial from the exterior stop bar of the first intersection, through the interchange's first intersection, and to the stop bar location in the same direction in the interior of the interchange at the second intersection. The interior queue storage is being computed as the number of vehicles that can be safely stored in the interior of the interchange for the left and through movements. Some adjustment to this vehicle length may have to be made if a significant percentage of heavy trucks are found in the traffic stream. If necessary, you can manually adjust these values later in the Advanced subfolder.

Phasing Subfolder

The choices that you make in the Phasing subfolder (Figure 31) impact both the types of analysis that you will have PASSER III^{TM}-98 perform for you, and the nature of the output produced by the program. Select the phasing sequence option(s) you are willing to consider in your analysis. For all types of interchange analysis, the program will produce output that a traffic engineer can use to provide timing inputs for diamond interchanges. If you select one of the standard phasing options, you have the option of having PASSER^{TM} III-98 optimize the internal offset for you (preferred), or you can specify a value by manually entering it.
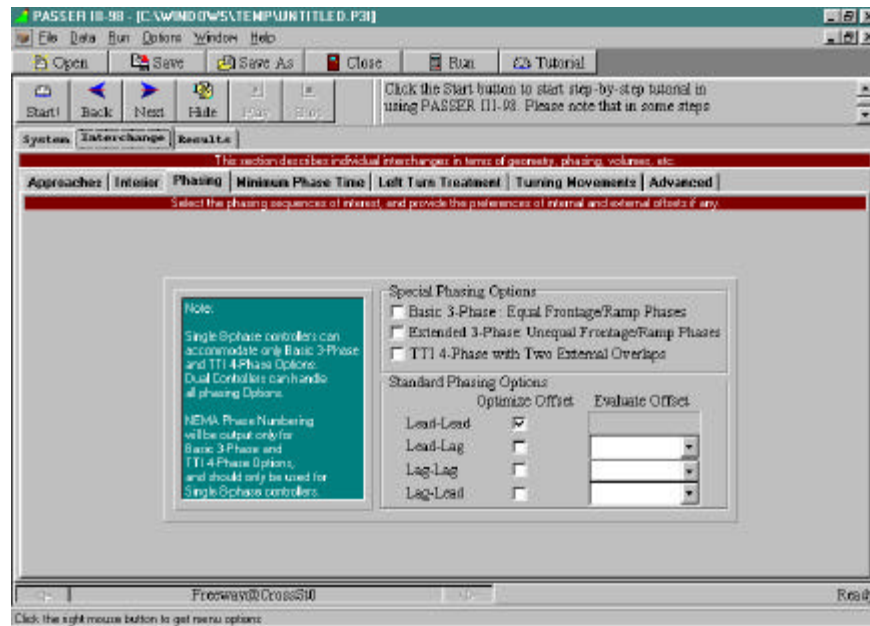
Figure 31. Phasing Subfolder Data Entry

Minimum Phase Time Subfolder

The data to be entered in the Minimum Phase Time subfolder (Figure 32) is the minimum phase time in seconds for each approach to each intersection of the diamond interchange. The minimum phase time (green + yellow + all red) is the least time you would like to assign to an approach when the program performs an optimization to determine the phase times for the interchange. The minimum phase times should also be long enough to ensure adequate walk and pedestrian clearance time for pedestrians crossing the other street if pedestrian detection is not used (see section 1.2.5). It is essential that the sum of minimum phase times for all the phases on the right (or left) side intersection must be less than or equal to the minimum cycle length entered in the General subfolder of the System folder. If you would like to simulate existing conditions at an interchange, the minimum phase time that you enter should be set to the existing phase times for each of the approaches.

Information concerning the setting of minimum green times can be found in Section 1.2.3. Minimum times input into PASSER^{TM} III-98 are split times, which means that they include the minimum green time, yellow change interval, and red clearance interval for each movement. Bear in mind that in actual implementation, a movement may be serviced by more than one phase (i.e., using an overlap). Each phase, whether or not it composes an overlap, must be provided with adequate minimum green, yellow change interval, and red clearance interval. All PASSER^{TM} III-98 output must be reviewed with these minimum and clearance interval times in mind. In some cases, it may be necessary to alter a timing plan output by PASSER^{TM} III-98 (i.e., increase phase times, and, thus, the cycle length) to provide adequate minimum green and clearance times.   Once these adjustments to minimum movement split times have been determined and made, PASSER^{TM} III-98 can be run to generate a final output file and/or report. Minimum green times must also consider pedestrian time requirements at each intersection (see Section 1.2.5).

45

Figure 32. Minimum Phase Time Data Entry

Left Turn Treatment Subfolder

Under the Left Turn Treatment subfolder (Figure 33), select the type of left turn treatment you would like analyzed for both of the interior approaches within the interchange. Your options are either a combination of protected and permissive left-turn phasing (i.e., circular green with green arrow followed by circular green, or vice versa) or protected phasing only (i.e., left turns are only allowed under a green arrow indication).

Figure 33. Left Turn Treatment Data Entry

Protected left-turn phasing allows the left-turning traffic to make the turn freely, without any conflicting vehicular traffic. Permissive left-turn phasing allows the left-turning traffic to make the turn by using the gaps in the opposing through traffic (i.e., the left-turning traffic has to yield to the opposing through traffic). In both cases, you must make sure that the field controller and signal heads are equipped to accommodate your left-turn phasing selection (see section 2.3.1).

Turning Movements Subfolder

The Turning Movements subfolder (Figure 34) is where traffic volume information is entered into PASSER™ III-98. From your turning movement counts at the two intersections of the diamond, enter in the arterial and frontage road volumes in vehicles per hour for each movement of each approach. Note that once you enter in the volumes on the exterior approaches, PASSER™ III-98 automatically computes the left turning and through movement volumes for the two interior approaches (i.e., the two approaches with data entry boxes with a gray background).
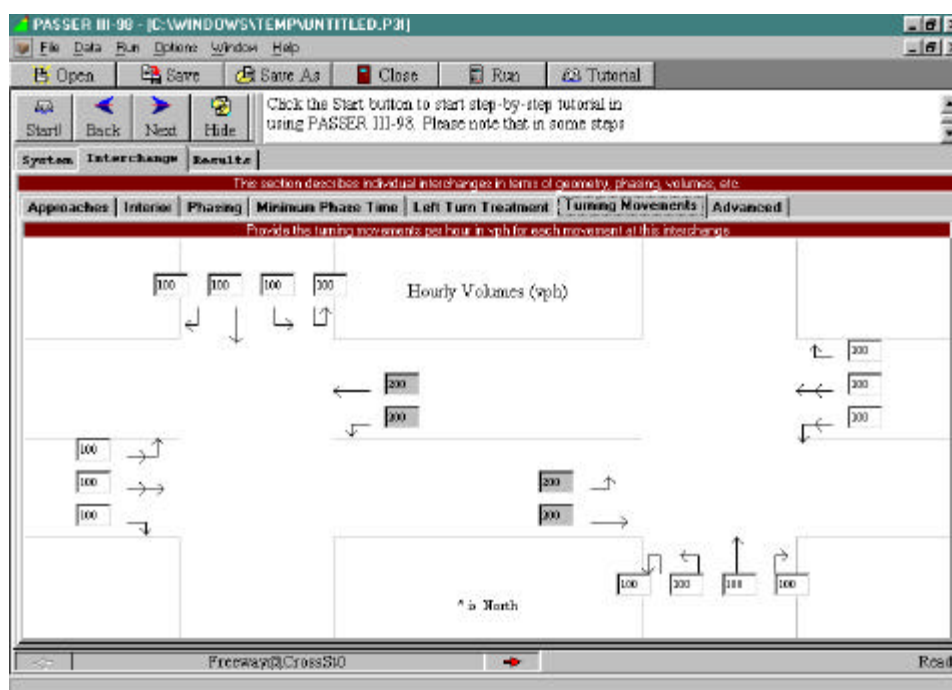

Figure 34. Turning Movements Data Entry

It is important that you only enter volumes that pass through the signal-controlled portion of each interchange intersection. Two common examples of volumes that are collected but should not be entered into PASSER™ III-98 are U-turn volumes where there is a U-turn bay and/or lane upstream of the interchange along the frontage road, and right-turn volumes where there is a right-turn bay or lane that is separated from the through movement with an island. In most cases, especially in low-to-moderate volume situations, even a "free" right turn cutout from a shared through+right lane is enough provision for right turns on red to preclude their addition to the volumes which are signal controlled. Adjustments for impedances to through movements and adjustments due to turning speed are discussed in the HCM (*3*). If U-turn volumes are not

known (in the absence of a U-turn lane) and frontage roads are present, use half the left-turning volume from the frontage road (or ramp) to the arterial as left-turning volume and the other half as U-turning volume. If no frontage road exists, use all the left turning volume from the ramp to the cross street arterial as left turning volume and none as U-turning volume.

Advanced Subfolder - Saturation Flow Values

The Advanced subfolder (Figure 35) is used to manually enter in values for the interchange's saturation flow rates, interior travel times, and interior storage. Values can only be entered/edited within this subfolder if the "AutoCalculate" option for each item (i.e., saturation flow, travel time, storage) is unchecked in the Data menu. You will probably only manually enter values if you have descriptive field data for the interchange that is not consistent with the values PASSER™ III-98 automatically computes based on interchange geometry. Usually, PASSER™ III-98 is left to automatically compute these calibration settings.

If you have headway or other field data that can be used to compute field-data based saturation flow rates, click on the Data menu option at the top of the screen and remove the check mark against the "AutoCalculate Saturation Flow Rates" option. Then, enter the prevailing saturation flow rates for each of the movements in the corresponding fields. Reasonably accurate values should be established for saturation flow since green times are calculated based on the movement's volume-to-saturation flow ratio. The saturation flow rates can be estimated using the techniques presented in the HCM (*3*). Otherwise, the program calculates the saturation flow rates based on the ideal saturation flow rates, lane assignment, lane width, etc.
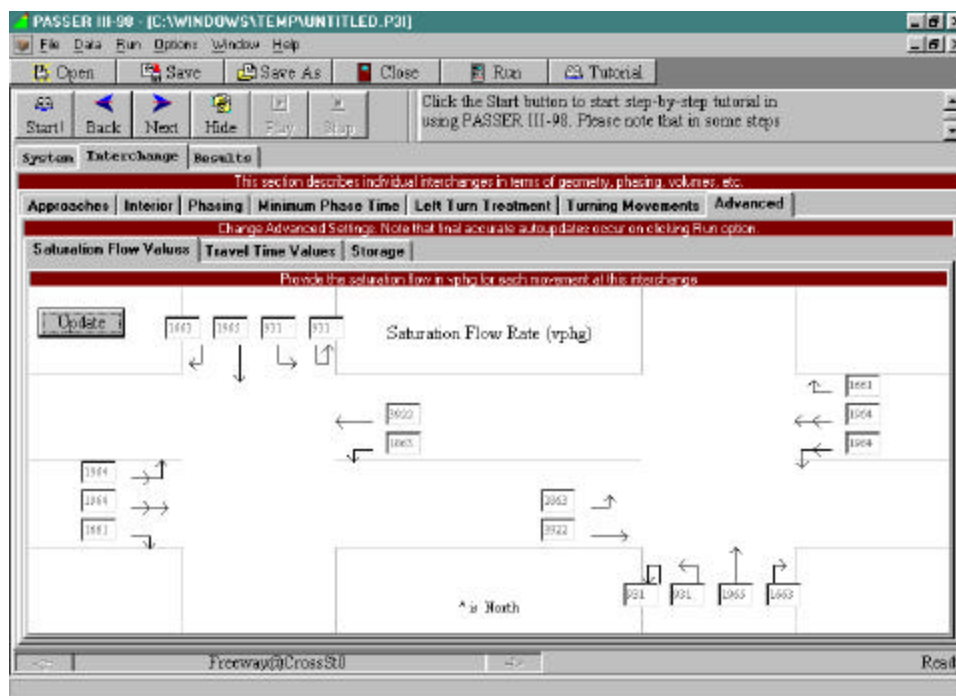

Figure 35. Advanced Subfolder - Saturation Flow Values

Advanced Subfolder – Travel Time Values

Interior travel time is the running travel time in seconds following onset of green for vehicles starting from the stop line at the left (right) side intersection to the stop line at the right (left) side intersection. If field data are available, click on the Data menu at the top of the screen and remove the check mark against "AutoCalculate Internal Travel Times" option. Then, enter the interior travel time on each of the internal links in the corresponding fields (Figure 36). If field data are not available, estimates of the travel time required for a queue of vehicles stopped at one intersection to start up and travel across to the adjacent intersection are given in Table 4. The program estimates these values for you based on the link speed and interior link length. For TTI four-phase operation, fixed interval transition is the time interval when the frontage road (or ramp) on the right-side intersection and the arterial through at the left-side intersection of the interchange are both green, and vice-versa.
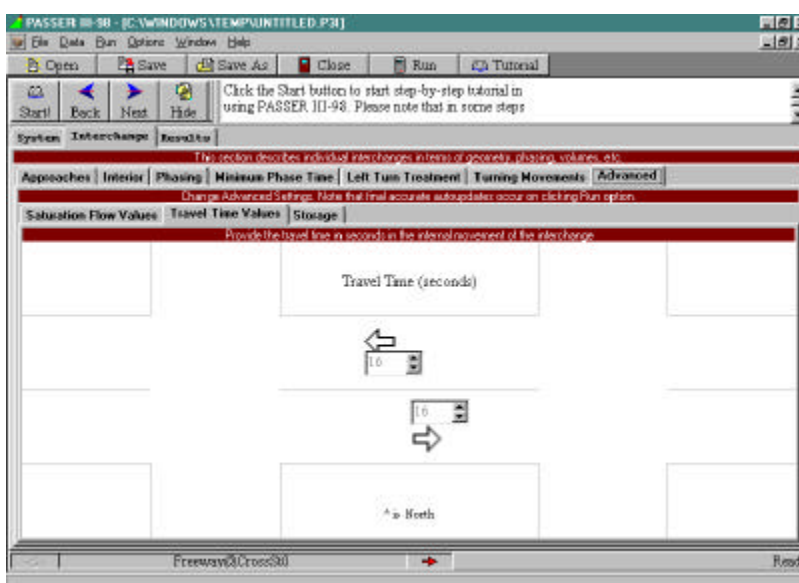

Figure 36. Advanced Subfolder – Travel Time Values

Table 4. Interchange Interior Travel Time and Fixed Interval Transition

Distance (feet)	Travel Time (seconds)	Fixed Interval Transition (seconds)
67	6	4
94	7	5
125	8	6
160	9	7
200	10	8
244	11	9
288	12	10
332	13	11
376	14	12
420	15	13

For an intersection spacing of x feet, and a maximum desired speed of V_{max} (fps), calculate travel time as follows:

$$t' = 0.225\ V_{max} + 0.5 \text{ (time after which } V_{max} \text{ is reached);} \tag{7}$$

$$x' = 0.1125\ (V_{max})^2 \tag{8}$$

The travel time is then given by:

$$t = \sqrt{0.45 \cdot x} + 0.5 \qquad \text{if}\ \ x \le x' \tag{9}$$

$$t = t' + \frac{x - x'}{V_{max}} \qquad \text{if}\ \ x > x' \tag{10}$$

Some modifications due to grades, heavy truck traffic, or high-quality cross street progression effects may be desired.

Advanced Subfolder – Storage

Storage defines the number of vehicles, corresponding to the appropriate movement, which can be stopped within the interchange without impeding crossing traffic on the frontage roads or ramps. An estimate of queue storage can be obtained by assuming that one passenger car occupies 23 feet of lane space. Multiple lane storage must be added, and a single lane may share storage between left-turn and through movements. If field data is available (i.e., based on field counts of how many vehicles are safely stored in the interchange interior for each movement), click on the Data menu at the top of the screen and remove the check mark against the "AutoCalculate Storage" option. Then, manually enter the interval storage values (Figure 37).
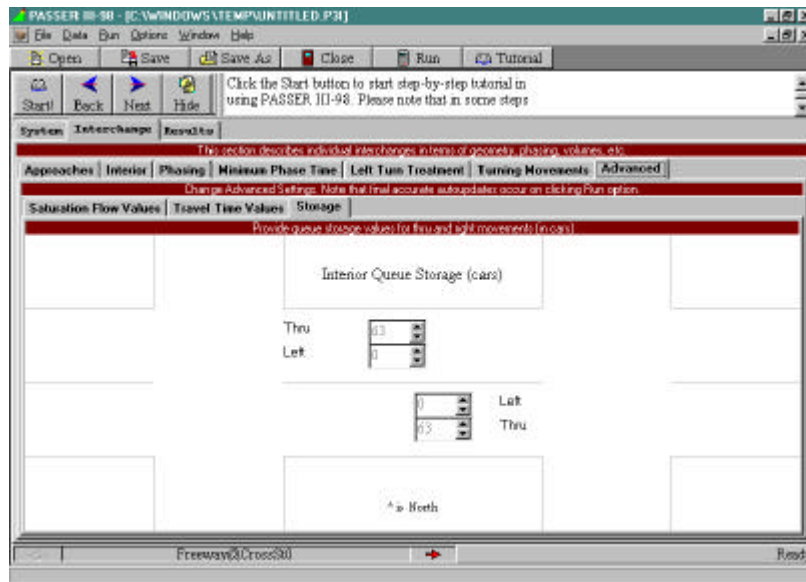

Figure 37. Advanced Subfolder - Storage Values

Completing Data Entry and Running PASSER^{TM} III-98

If you have only one interchange, you have completed data entry. You may wish to review your data to ensure that all entries have been coded correctly. When you are satisfied that your input is correct, select the Run menu at the top of the screen and mouse-click "Run PASSER^{TM} III-98." The program will execute and you will see a temporary screen appear indicating that PASSER^{TM} III-98 is processing and analyzing your interchange. If coding errors are found, you will be notified. Correct the problem and run PASSER^{TM} III-98 again. Once all errors are resolved and you have run the program, you are ready to read and interpret the output.

If you have two or more interchanges, you must repeat the data entry process you have just completed until all of your interchanges have been fully and correctly coded. Also, keep in mind that to coordinate frontage road operations of adjacent interchanges, you must provide information about the segments of frontage road between them in the Frontage subfolder of the System folder. It is recommended that you complete data entry for each interchange completely before moving on to the next interchange. The consistency created by coding one interchange at a time will reduce coding errors. To assist you in working with multiple interchanges, you can mouse click the red arrow on the status bar at the bottom of the screen to advance from one interchange to the next.

When you have completed data entry for all interchanges and frontage road links, and you have checked all of your data for accuracy, you are ready to run PASSER^{TM} III-98. Select the Run menu at the top of the screen and mouse-click "Run PASSER^{TM} III-98." The program will execute and you will see a temporary screen appear indicating that PASSER^{TM} III-98 is processing and analyzing your interchange. If coding errors are found, you will be notified. Correct the problem and run PASSER^{TM} III-98 again. Once all errors are resolved and you have successfully run the program, you are ready to read and interpret the output.

3.4   PASSER^{TM} III-98 Output: The Results Folder

PASSER^{TM} III-98 produces a dynamic database of analysis results, a graphical display of many measures of system performance, a rich text format (RTF) report file that can be read into your word processor, a graphical simulation of interchange operation, and a general output file that is similar to the output files from previous versions of PASSER^{TM} III.

3.4.1   System Summary Subfolder

A very powerful tool for identifying optimal solutions from the program is the dynamic database of analysis results found in the System Summary subfolder (Figure 38). Shown in the sample output screen below, this subfolder contains an organized listing of the outputs for the cycle length and phasing sequence combinations that you had PASSER^{TM} III-98 examine. Cycle length and phasing sequence are displayed on the left side of the screen, and for each combination the measures of effectiveness (MOEs) are listed.

By default, output is organized from least total delay to most total delay. The data can easily be resorted by clicking another MOE. For instance, by mouse-clicking on the words "Total Cost," the data would be sorted from least operating cost to highest operating cost. If you are searching for output for a specific cycle length/phasing sequence combination, it can be selected from drop-down boxes near the top of the subfolder. This output is only available if you are analyzing a single (isolated) interchange.
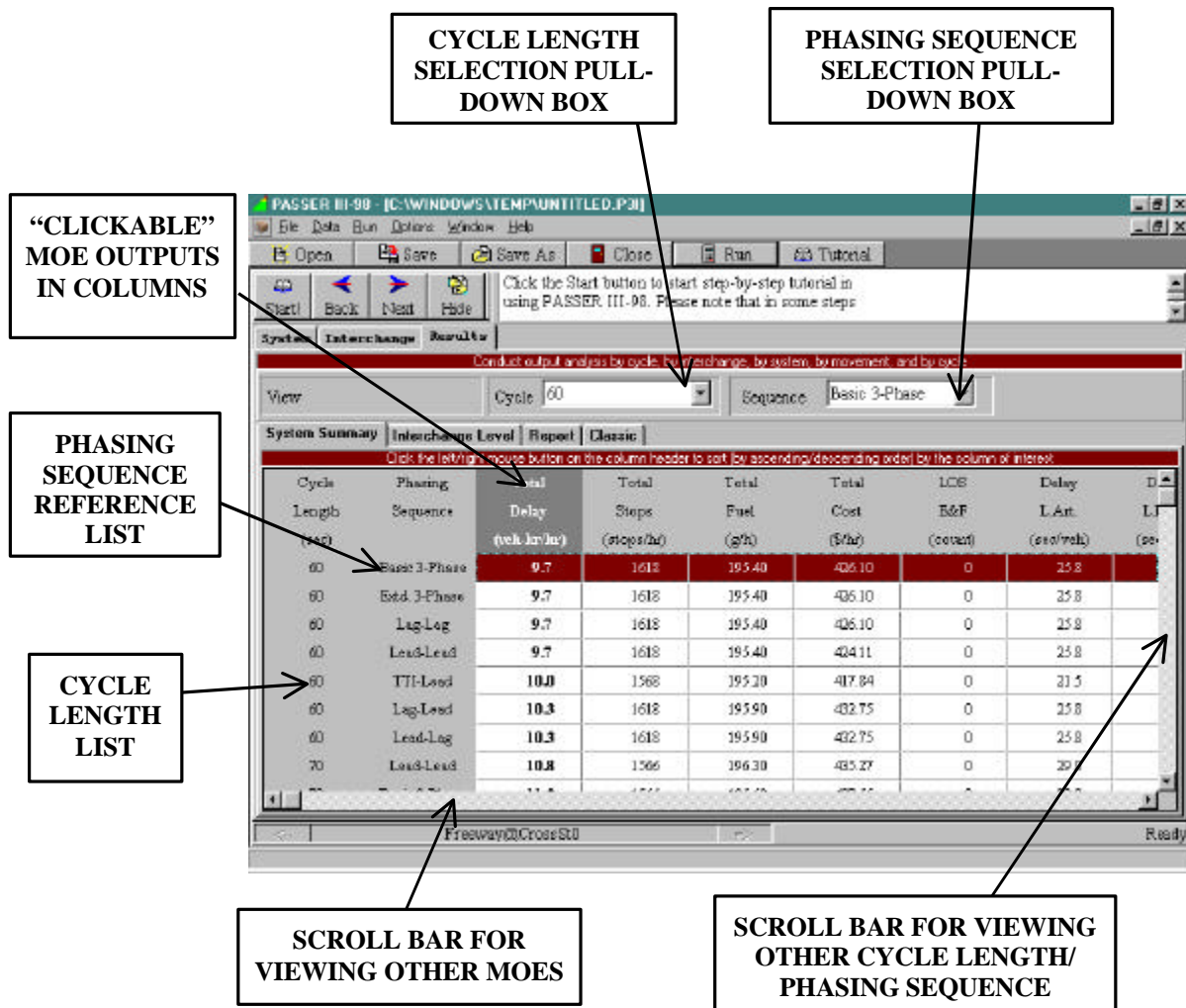
Figure 38. System Summary Output

3.4.2   Interchange Level Subfolder

Another means of presenting the data produced by PASSER™ III-98 for the various cycle length and phasing sequence combinations you analyzed is a graphical output screen (Figure 39). Three pull-down boxes at the top of the Interchange Level subfolder allow you to select the MOE you would like to view, and the cycle length and phasing sequence for which you would like results displayed. The output is color coded so that you can easily identify if and where problems occur for a particular MOE and cycle length/phasing sequence combination. The output contained in this subfolder is only available if you are analyzing a single (isolated) interchange.
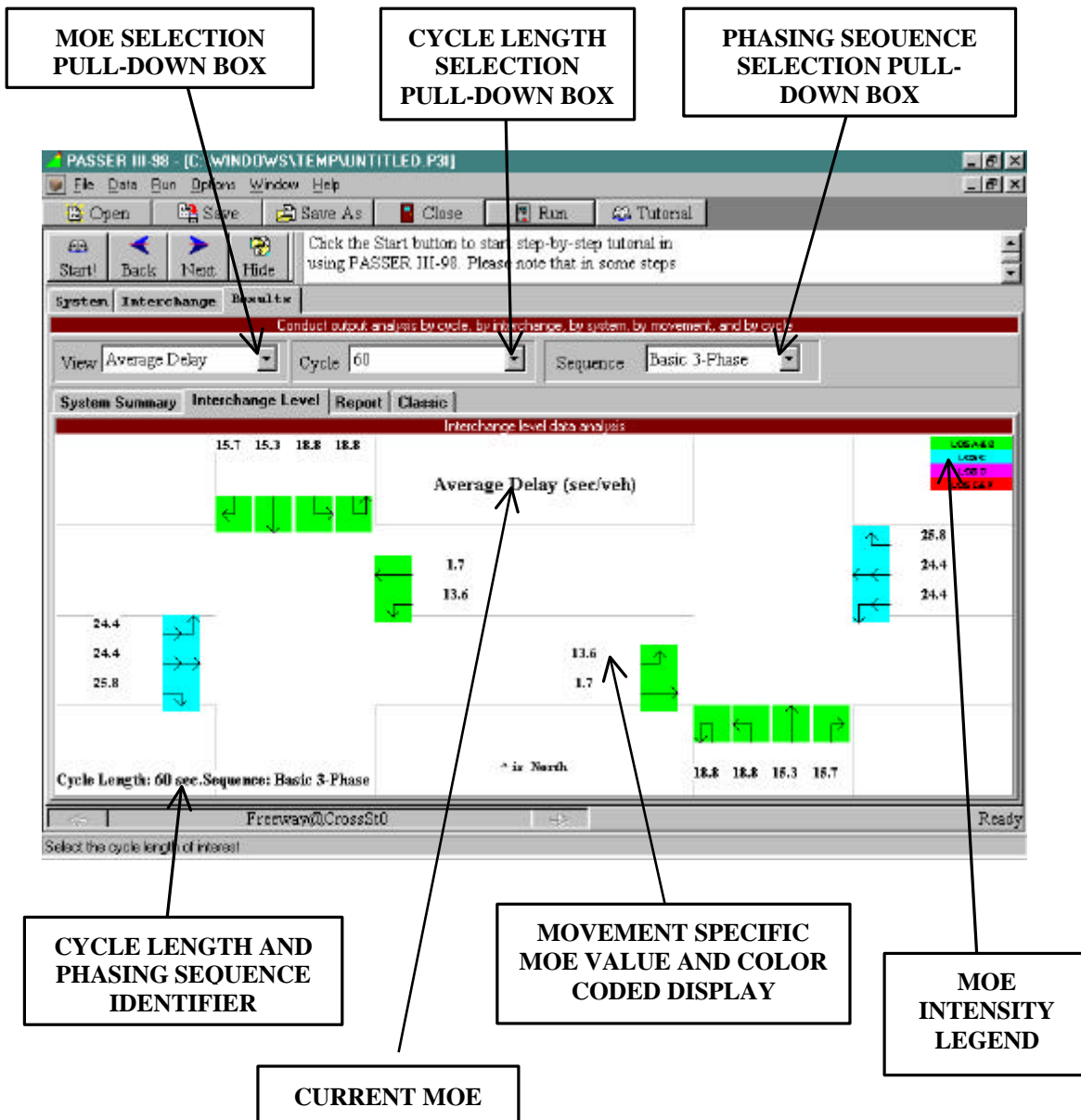
Figure 39. Interchange Level Output

3.4.3   Report Subfolder

Contained within the Report subfolder (Figure 40) is the ability to generate a rich text format (RTF) file that you can import into a word processor or automatically view if you have a viewer (i.e., Microsoft® Word viewer) available and linked with PASSER™ III-98. Also available from this subfolder is the ability to access a simulation of interchange operations that you have analyzed. For both the report and the simulation, the cycle length and phasing sequence you wish to examine should be selected from the pull-down boxes at the top of the Report subfolder. The report and animation can only be accessed for single (isolated) interchange analyses.
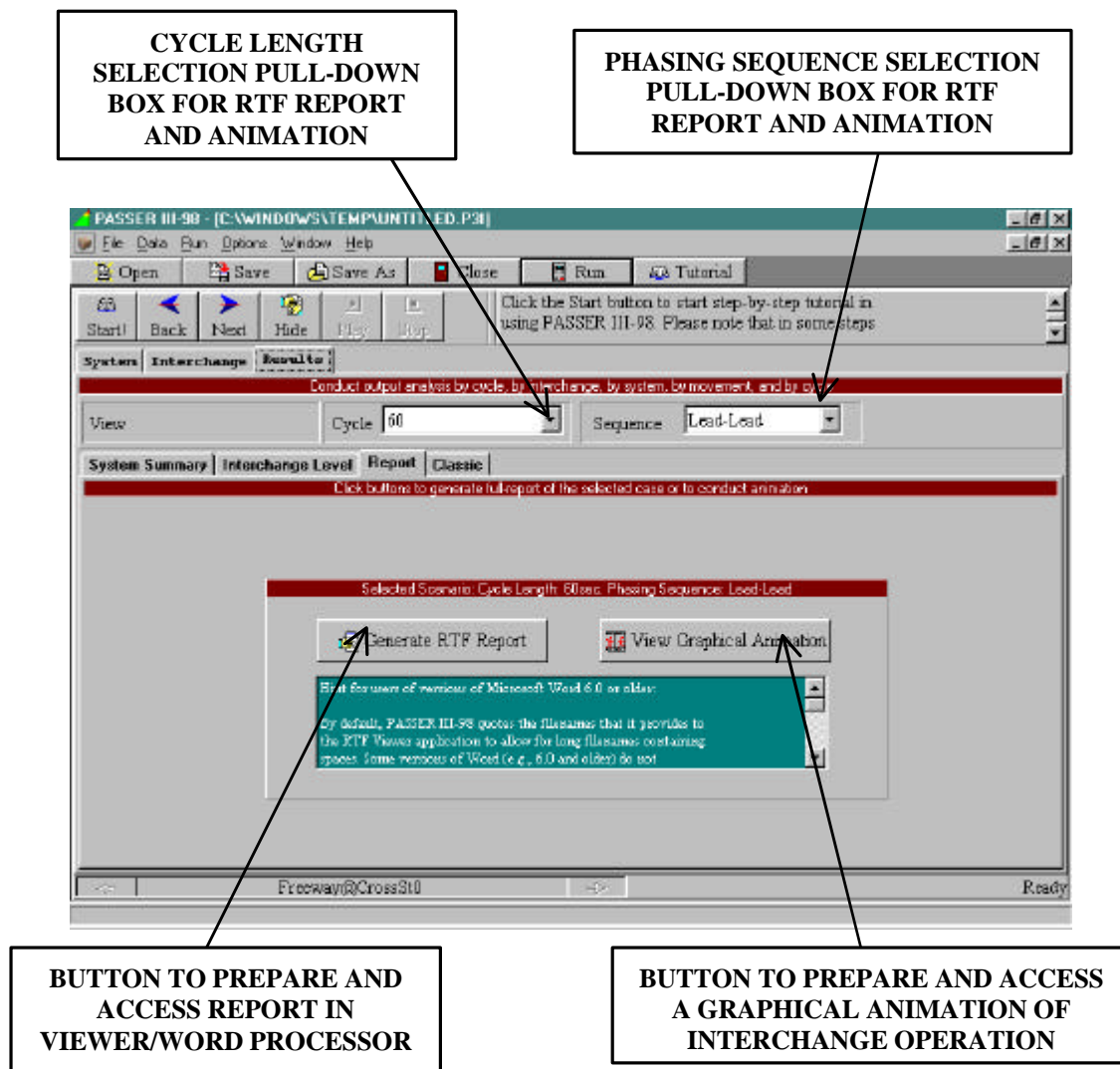

Figure 40. Report Output and Animation Viewer

Generate RTF Report

If you select rich text format (RTF) file generation, you will automatically be forwarded to your RTF viewer/word processor. The screen example below uses Microsoft® Word as the viewer (Figure 41). The report contains complete documentation of your input coding, the analyses performed, and specific output for the cycle length/phasing sequence you selected in the Report subfolder. A table of contents for the report is provided, and you can easily move to the various report sections by clicking on the page number associated with the desired section. Within some word processors, it may be necessary to press Ctrl-A, then F9 to update page numbers in the table of contents.
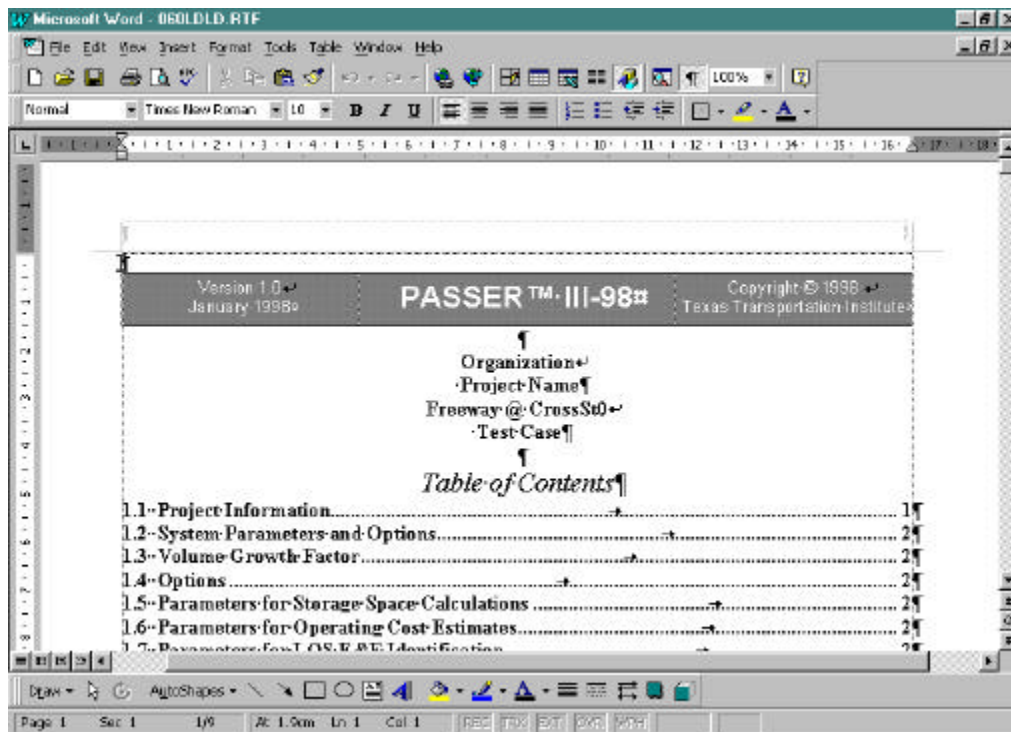

Figure 41. Sample RTF Output Report

PASSER^TM III-98's RTF report serves as complete documentation of input and output for the specified cycle length and phasing sequence you select in the Report subfolder. To document a complete analysis from a variety of cycle length/phasing sequence combinations, you may wish to generate multiple RTF reports (one for each cycle length/phasing sequence) and use your word processor to edit them into a complete analysis file.

The report generated for you is broken up into five sections. A generic table of contents for the report is shown in Table 5. You may find this table of contents helpful if you are searching for specific types of information in the output file. Report section five contains the phase settings that can be entered into a field controller to implement the cycle length and phasing sequence for which the RTF report was generated. All timing plan elements must be approved by a licensed engineer and calibrated, or fine-tuned, in the field to account for local conditions.

Table 5. Table of Contents for PASSER^{TM} III-98 RTF Report

Report Section	Section Title
1.1	Project Information
1.2	System Parameters and Options
1.3	Volume Growth Factor
1.4	Options
1.5	Parameters for Storage Space Calculations
1.6	Parameters for Operating Cost Estimates
1.7	Parameters for LOS E&F Identification
1.8	Notes
2.1	Interchange
2.2	Phasing Data
2.3	Approach Data
2.4	Interior Link Data
2.5	Movement Data
3.1	System Performance Summary of Signal Timing Plans Analyzed
4.1	Movement Performance
4.2	Approach Performance
4.3	Interchange Performance
4.4	LOS E&F
5.1	Timing by Phase Interval
5.2	Movement Timing for Dual Controllers
5.3	Controller Timing Plan (8-Phase Controllers Only)

View Graphical Animation

PASSER^{TM} III-98 contains a graphical animation viewer (Figure 42) that allows you to view a simulation of a diamond interchange operating with the geometry and volumes that you entered into the program and the cycle length/phasing sequence you selected from the Report subfolder. You have control over starting, pausing, and stopping the animation. You can also zoom in and out to focus the view on various aspects of interchange operation. A progress indicator shows you how far into the 15-minute animation you have already progressed. Also, a phasing indicator shows the active green display at each exterior and interior approach to the interchange.

The simulation gives you a clearer understanding of the way that the phasing sequence allows or does not allow for progression through the interior of the interchange. It can also help you identify where queuing may be a concern within the interchange.

When you have completed viewing your interchange using the animation program, mouse-click "File" to access the File menu and select "Exit."
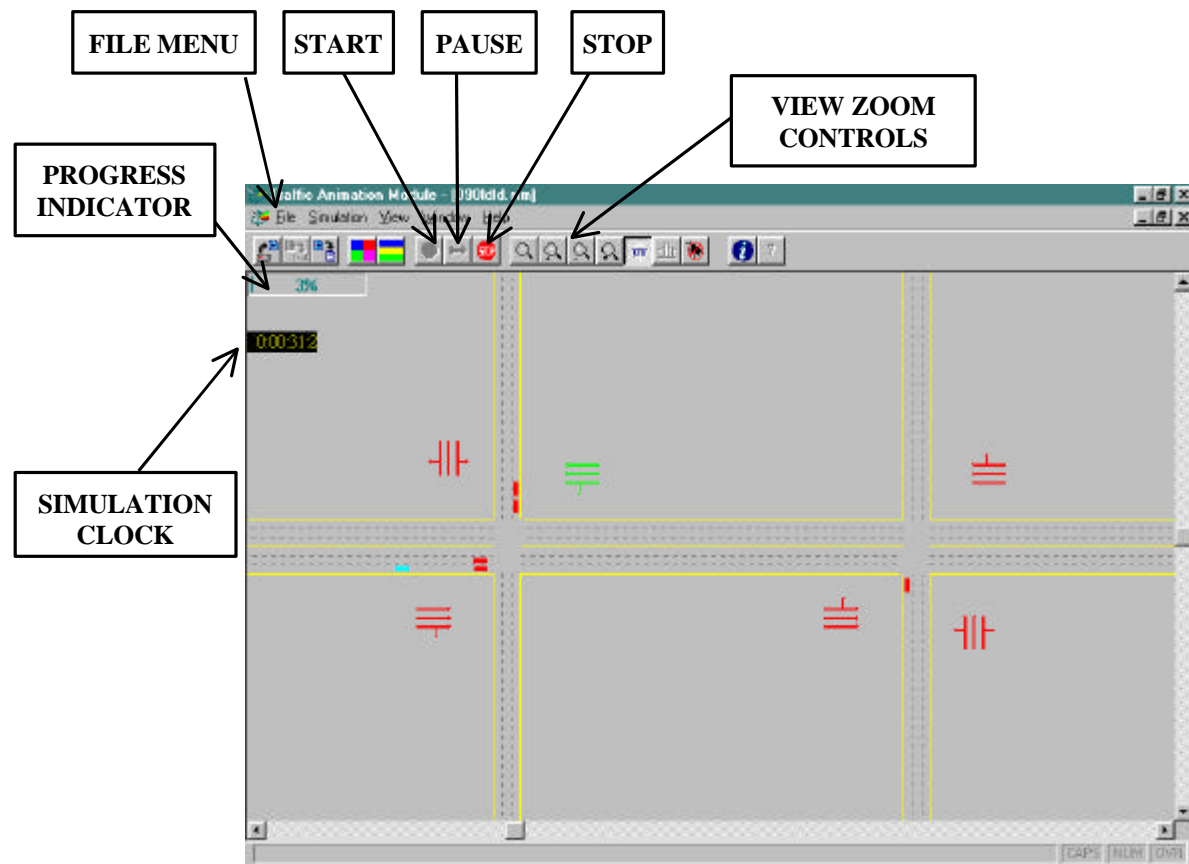

Figure 42. Graphical Animation Viewer

3.4.4 Classic Subfolder

The PASSER^{TM} III-98 Classic subfolder (Figure 43) is the means of obtaining individual pieces of program output without having to generate an entire RTF report under the Report subfolder. It is also the location of output data pertaining to multiple interchange analysis runs. The "Classic" name is used because the output information accessible from this screen is similar in format to the output produced by the previous versions of the PASSER^{TM} software.

As shown in the screen graphic below, information is presented under "tabs." Also, buttons are located at the bottom of the screen that allow you to print the information under each tab or copy that information to the Windows® 95 clipboard. Data that is copied to the clipboard can then be "pasted" into run documentation or analysis reports that you generate separately using a word processing program. The data available under the tabs is based on the cycle length and phasing sequence that you specify from the pull-down boxes at the top of the Classic subfolder.

Some of the tabs are accessible only if you analyze multiple interchanges. Table 6 lists which tabs are available for isolated and multiple interchange runs.
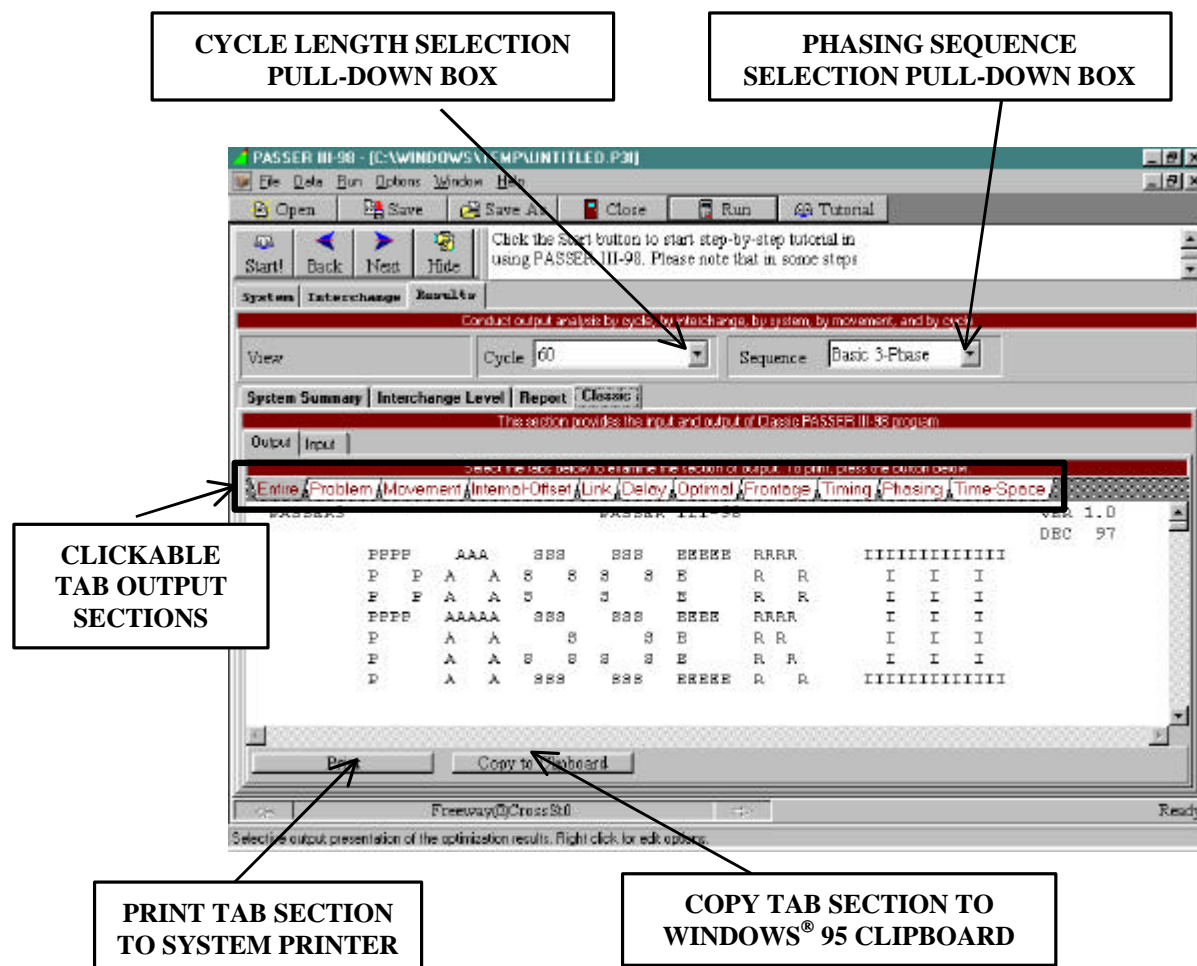

Figure 43. PASSER^{TM} III-98 Classic Output

Table 6. PASSER^{TM} III-98 Classic Output by Type of Analysis

Individual (Isolated) Interchange	Multiple Interchanges
Entire	Entire
Problem	Problem
Movement	Movement
Internal Offset	Internal Offset
-	Link
Delay	Delay
-	Optimal
-	Frontage
Timing	Timing
Phasing	Phasing
-	Time/Space

The following paragraphs describe the information contained within each of the Classic subfolder tabs:

Entire - This tab can be mouse clicked to see the entire output file from PASSER™ III-98. This includes the input and the output information presented in the classic format.

Problem - The first part of this tabbed screen contains general information that is used for identification purposes. The input echo includes the freeway name, city name, district number (if applicable), date of the data collection or analysis run, and run number. If a single interchange was analyzed, this screen also contains the lower and upper cycle length range used in the analysis, the cycle length increment, and whether the program optimized or evaluated internal offsets for the interchange. If multiple interchanges were analyzed, this screen contains the number of interchanges, the lower and upper cycle length range, the cycle length increment, directional band splits, whether the program optimized or evaluated internal offsets, whether or not link speed variation was allowed, and whether the program optimized or evaluated external offsets.

Movement - The first section of this tabbed screen contains the volumes (vph), saturation flows (vphg), and minimum greens (sec) for each of the movements at the left-side intersection of the interchange. The second section of the screen contains the same information for each of the movements at the right-side intersection of the interchange. The identification number and name of the interchange, along with the identification number for this particular alternative analysis, are shown on the top line of each screen section.

Internal Offset - This tabbed screen contains information about the types of phasing sequences, selected by the user, for program evaluation. For each sequence, it indicates whether PASSER^{TM} III-98 was to optimize the internal offset or use an offset specified by the

user. This screen also shows the computed interior queue storage within the interchange for left-turning and through vehicles, whether or not permitted left turns were allowed, and the calculated interior travel times for the interchange.

Link - The Link tab contains information about the frontage road segments that was input for a multiple interchange analysis. For both the 'A' and 'B' direction frontage roads, this information includes the link name, distance (feet), speed (mph), and queue clearance (seconds).

Delay - This tabbed portion of the output contains a plot of delay versus offset for each delay-offset analysis that was conducted. The interchange number, cross-street name, type of phasing, and cycle length are shown on the top of each line of each plot, and the internal offset which produces the least delay to the interchange is shown on the bottom line. Between these two lines of description, a scaled plot of the delay-difference-of-offset relationship for the traffic, geometric, and signal timing data input to the program are presented. The internal offset (i.e., difference in time between the start of the arterial phase at the left-side intersection and the end of the frontage road (or ramp) phase at the right-side intersection of the interchange) increases from left to right and is shown along the horizontal axis. The total delay experienced by all vehicles using the interchange in an hour is shown on the vertical axis and increases from bottom to top. The "***" represents the estimated total delay for each of the possible offsets between the two signals at the interchange.

Optimal - Beneath the Optimal tab is information about the optimal cycle length (sec) for a multiple interchange analysis. Both frontage road progression speed (mph) and progression bandwidth (sec) are displayed for the 'A' and 'B' direction frontage roads. Finally, the progression efficiency (i.e., the average fraction of the cycle length used for progression) and the attainability (i.e., the average fraction of the frontage road green for each direction that are found in the progression bands) are reported. Better solutions have efficiencies in the range of .35 to .45 and attainabilities close to or equal to 1.00.

Frontage - The Frontage tabbed section contains information about the cross street name at each interchange, the signal phasing sequence, the internal offset within the interchange, the external offset between interchange pairs, and the 'A' and 'B' direction travel times. The external offset is defined as the difference in time between the start of the arterial phase at the left-side intersection of the first interchange in the 'A' direction and the start of the arterial phase at the left-side intersection of successive interchanges downstream along the frontage road.

Timing - This tabbed section contains the general output for each interchange. For each interchange phase (i.e., for both the left and right intersections), the phase time (sec), volume to capacity ratio, delay (sec/veh), and storage ratio is reported. Better solutions have a balance across the interchange and delays and v/c ratios that tend to be similar for most interchange movements. One or two approaches should not have an inequitable delay burden. For the overall interchange, the phase sequence, internal offset (sec), total interchange delay (sec/veh), and level-of-service are reported.

Phasing - The Phasing section displays the necessary information for the desired cycle length/phasing sequence combination. The data is organized by phase interval numbers, and for each interval a duration (sec) is given along with the appropriate phasing codes for the left and right side intersections. For the overall interchange, the internal offset (sec), cycle length (sec), external offset (sec), and phasing sequence are displayed.

Time/Space - This tabbed portion of the output file contains information if multiple interchanges were analyzed as a progressive system. The city name, district, run number, and horizontal scale are listed on the first line of this screen, and the freeway name, cycle length and vertical scale are listed on the second line. Additionally, the 'A' and 'B' directions' average progression speeds and bandwidths are listed on the last two lines of the file. Between these two blocks of descriptions is a scaled plot of the time-space diagram (TSD) for the optimal progression solution. Time increases from left to right and is shown along the horizontal axis. Space or distance increases from bottom to top and is shown on the vertical axis. Interchange locations and external offsets, in both seconds and percent of cycle length, are also shown on the vertical axis. At each interchange, the status of the traffic signal at the left-side intersection is illustrated on the bottom horizontal line, and the status of the traffic signal at the right-side intersection is illustrated on the top horizontal line. The status of the signals at each interchange is indicated by the symbols on the TSD (i.e., whose legend is shown on the bottom of the TSD.). Progression bands (i.e., the dotted lines) go through the blanks in the bottom line for the 'A' direction (i.e., vehicles traveling from lower left to upper right on the screen) and through the blanks in the top line for the 'B' direction (i.e., vehicles traveling from upper left to lower right on the screen).

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4.0 PASSER^{TM} III-98 EVALUATION AND OPTIMIZATION PROCEDURE

An example problem serves as the best means for outlining a preferred method for using the PASSER^{TM} III-98 software for diamond interchange analysis. The example chosen is based on actual field data. Each step of transferring field geometric, signalization, and volume information into the program is fully documented.

The first stage of diamond interchange analysis is to evaluate current performance by visiting the field. A field evaluation should also be used to verify the performance (i.e., delay, v/c ratio, etc.) of existing conditions estimated by PASSER^{TM} III-98. This information serves as a baseline for comparison to optimized results from latter steps in the analysis process.

4.1 Problem Description

The example interchange is located at the junction of Interstate 10 and Schloss Rd. in a suburban area of Mytown (Figure 44 and Figure 45). The interchange is isolated and it is considered a full diamond with frontage roads. The interchange currently operates under a three-phase, lead-lead phasing sequence and a cycle length of 90 seconds (Figure 46). The AM peak period is analyzed for this example.

Two-hour turning movement counts were conducted, with data recorded for each approach every 15 minutes. The peak 15-minute flow period was determined to be from 8:30 to 8:45 am. Figure 45 displays the design hourly volumes (peak 15-minute volume multiplied by 4) by movement. Since these volumes have already considered peaking (i.e., the peak 15 minute volume was multiplied by four to calculate them), no peak hour factor (PHF) is used when the volumes are entered into PASSER^{TM} III-98.
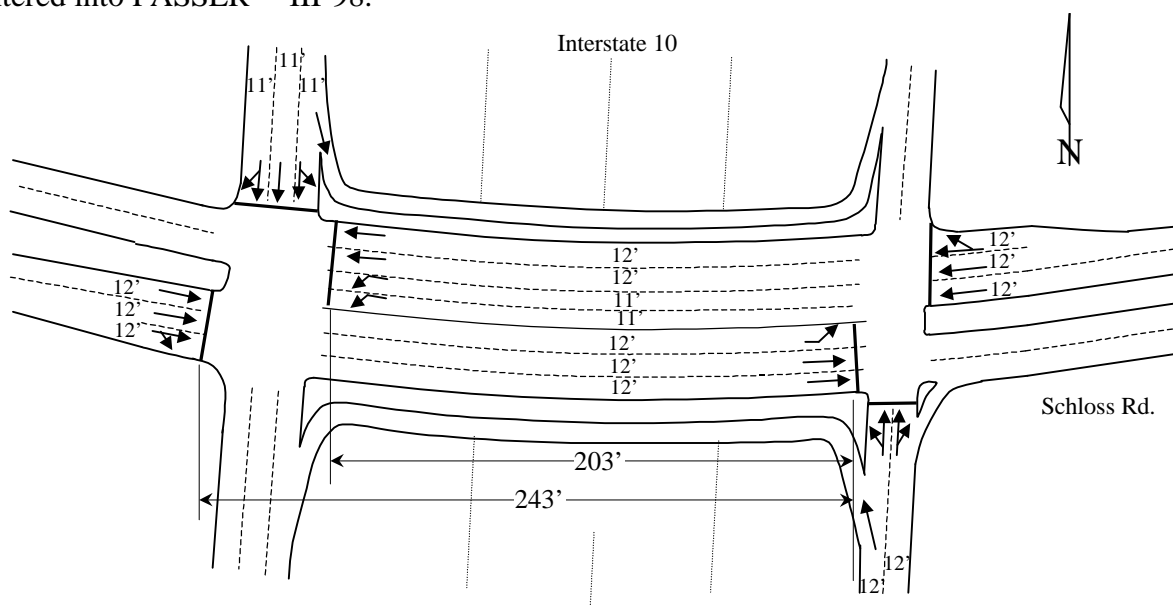

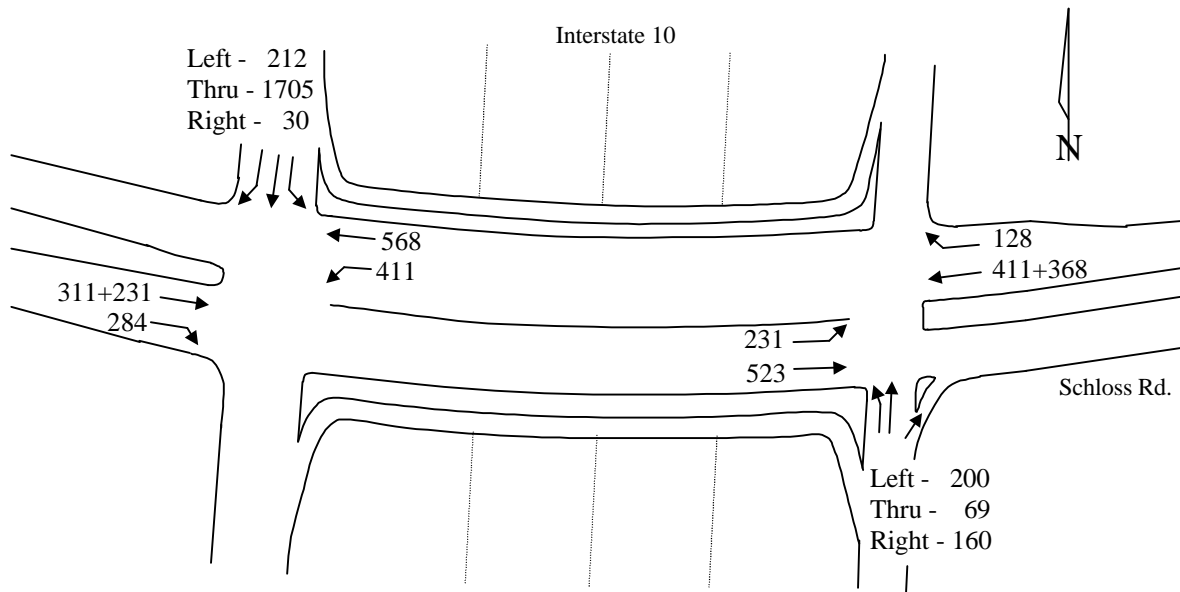**Figure 44. Example Interchange Geometric Data**

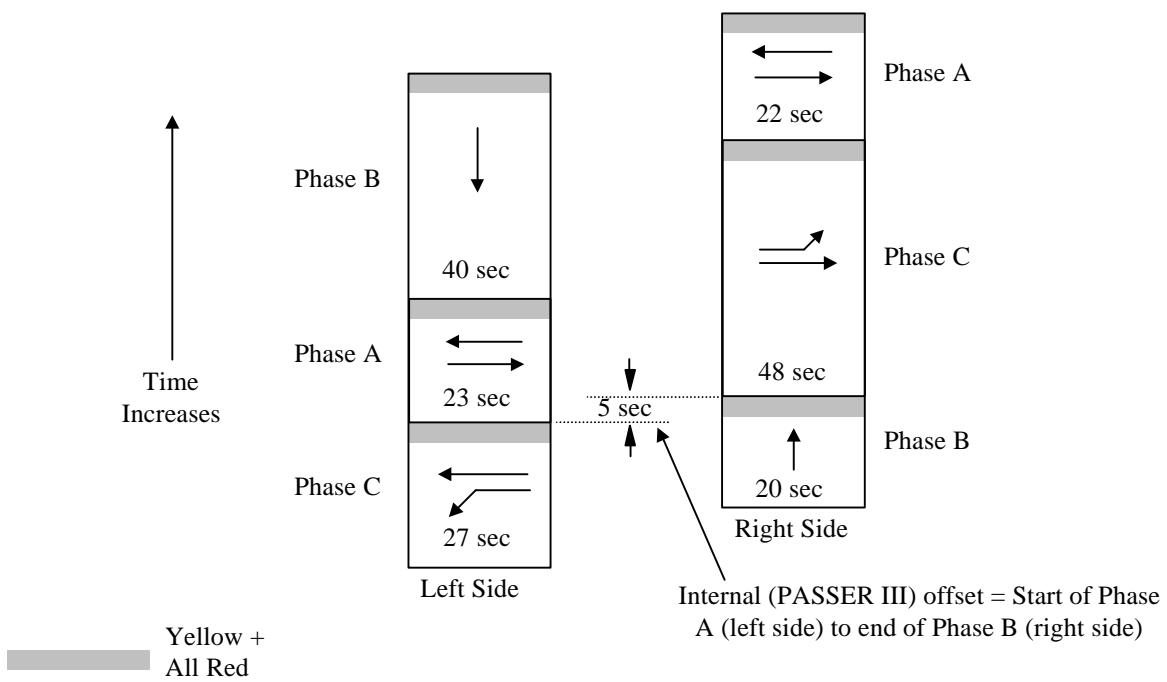**Figure 45. Example Interchange Volume Data**

Figure 46. Example Interchange Signal Timing Data

4.2   Evaluate Existing Operations

Initialization of the existing conditions analysis is started by clicking the PASSER^{TM} III-98 icon (or selecting Start|Programs|PASSER 2000|PASSER III-98 Version 1.0 from the Windows® 95/98 Taskbar). Proceeding from left to right, data should be input in each folder and subfolder within the folders. It is important to make notes during this data input as to where additional data is necessary. Another important "input" in PASSER^{TM} III-98 are the default settings that are used. The default value settings used in PASSER^{TM} III-98 are under the 'Data' Menu located in the File Menu Bar at the top of the screen.

4.2.1   Entering Data

'System' Folder | 'Project Information' Subfolder. Mouse click within each text box (or use the 'Tab' key) and enter in the appropriate information. Our city name is Mytown, our freeway name is Interstate 10, and our cross street name is Schloss Road. Enter "Evaluate Existing Conditions" as the case name.

'System' Folder | 'General' Subfolder. Enter the 90 seconds for both the "From" and "To" elements of the cycle length range, and enter in "0" as the increment because we are evaluting existing conditions. We are not evaluating future conditions, so leave the growth rate as "0." The other values within this subfolder will not require editing, as our North points to the top of the page in our example case and our traffic counts are hourly volumes that have already considered peaking characteristics (i.e., leave the Peak Hour Factor as 100%).

'System' Folder | 'Multiple' Subfolder. This is an analysis of a single interchange, so no data needs to be entered within this subfolder.

'System' Folder | 'Frontage' Subfolder. As previously mentioned, this subfolder is for the multiple interchange analysis. Since this is an analysis of a single interchange, no data needs to be entered within this subfolder.

'Interchange' Folder | 'Approaches' Subfolder. Enter the number of lanes, the lane use configuration, and the lane widths are entered within this subfolder for each approach. For this example, a zero grade and a truck percentage of zero for each approach are assumed (use field values in your analysis of real interchanges). Mouse-clicking the small circular selection box next to each lane group can access the lane groups for each approach.

'Interchange' Folder | 'Interior' Subfolder. Enter the length of the interior of the interchange (i.e., the length that can be safely used to store vehicles between the intersections). Our best estimate of this length is the 203' distance (i.e., our measured 243' minus 33' of frontage lane width and 10' stop bar setback) from the problem description. This distance will be used for both input locations for this example. It should be noted that there are cases where the distance may be slightly different because of horizontal curvature within the interchange. The number of bays and bay lane length entries do not apply in this example because there are no left turn "bays" within the interior of the interchange, i.e. all left turn movements are from full-length lanes (left-turn bays are supplemental lanes that do not cover the full distance between the

intersections). Assume that the speed of travel in each direction is 35 mph. PASSER^TM III-98 automatically computes the travel time and storage values for you.

'Interchange' Folder | 'Phasing' Subfolder. The internal offset given for this interchange was five seconds. This analysis of existing conditions should reflect this signal configuration and thus, the special phasing options and all standard phasing option boxes for "Optimize Offset" should remain unchecked. Simply select the value "5 sec" from the pull-down box under the "Evaluate Offset" entry for the Lead-Lead phasing option only.

'Interchange' Folder | 'Minimum Phase Time' Subfolder. For an evaluation of existing conditions, we must enter in the existing phase times as the minimum phase time entries on this screen. Review the timing recorded during the data collection effort and input the values in the appropriate locations. When you have completed this task, the screen should look like Figure 47.

Figure 47. Example Interchange Minimum Phase Data

'Interchange' Folder | 'Left Turn Treatment' Subfolder. Both the left and right side interiors currently operate using protected left-turn phasing only.

'Interchange' Folder | 'Turning Movements' Subfolder. Several significant points are worth noting about the volumes given for our interchange. First, notice that the frontage roads both have U-turn lanes along their approaches to the diamond interchange. Because traffic can freely make U-turns, and because U-turning traffic does not need to pass through the signalized portion

of the interchange, U-turn volume was not reported in Figure 45 and does not need to be entered into PASSER^{TM} III-98. Note that the arterial through volumes approaching from both the eastbound and westbound approaches are reported in two components – a volume that goes through the first intersection and then turns left at the second intersection, and a volumes that goes through the first intersection and then goes through the second intersection as well. Also note that the interior through volume (i.e., the 523 vehicles at the approach to the right-side intersection) is composed of through vehicles coming from the left-side arterial (i.e., 311 vehicles) and left-turning vehicles coming from the left-side frontage road (i.e., 212 vehicles). Experience will dictate how you have your field technicians report interchange counts; the above method is one means of clearly reporting which vehicles make turning maneuvers within the interchange. As TMC counts may not capture true turning movements through the interchange, it is good practice to get origin-destination information for the interchange. If origin-destination TMC data is not available, field observations may provide some insight as to the type of traffic patterns that exist, and supplement TMC data.

Another factor to consider is the prevalence of special conditions that affect traffic operations. Right turn on red (RTOR) traffic is one type of occurrence that changes the effective capacity of an approach. RTOR traffic is allowed to use the gaps created during change intervals and gaps in the opposing traffic to make a right turn maneuver. The volume of RTOR traffic should be reviewed in the field to identify the prevalence of lane blocking (shared lane) and "effective" reduction of traffic that needs green time.

Auxiliary lanes are also important to consider in the analysis. Auxiliary lanes are normally channelized right turn lanes that allow right turning traffic a chance to "avoid" the signal control, thereby using gaps in the opposing traffic similar to RTOR traffic. For our example different approaches must be treated differently. On the left-side frontage road (i.e., southbound), all right-turning vehicles must pass through the signal-controlled part of the intersection. However, there is a small right-turn lane on the right-side frontage road that is depicted with a small island, which effectively separates right-turns from the through traffic. In this case, right-turning traffic does not actually pass through the signal-controlled part of this intersection. Observing the drawing on the previous page, we note that the right turn lane is not very long, and that it diverges from the through lane just before the signal. Therefore, it is likely that a queue of through vehicles will partially block right-turners from reaching the right-turn lane in the first place.

Estimates based on field studies can be used to account for RTOR impacts (if present). It is estimated that one or two right-turning vehicles will probably be able to reach the right-turn lane each cycle before the right-turn lane is blocked by the through vehicle queue. Some simple mathematics indicates that there are 40 (i.e., 3600 seconds per hour divided by 90 seconds per cycle) cycles in an hour. If two vehicles can make free right turns every cycle, a total of 80 right-turners (i.e., 40 multiplied by 2 vehicles) can pass through the intersection without being considered as volume that must pass through the signal. Since our traffic counts indicate that 160 vehicles make this maneuver in the AM peak hour, and since 80 vehicles make "free" right turns on red through the right-turn lane, the volume that will be reported to PASSER^{TM} III-98 for the right-side intersection frontage road right-turn movement is 80 (i.e., 160 minus 80).

The above logic processes are all based on the fact that only volume which passes through the signalized intersections within the interchange should be coded into PASSER™ III-98. Judgement must be used where right-turn traffic may be reduced due to these conditions. If an exclusive right-turn lane or bay exists (and right-turn on red is allowed), the right-turning volume entered into the program is most likely going to be zero (0). When you have completed the volume data entry, your screen should look like Figure 48.

Figure 48. Example Interchange Volume Entry Data

'Interchange' Folder | 'Advanced' Subfolder. Let's examine this information as a check on our progress. Your saturation flow rates should be the same as those shown in Figure 49. Click on the "Update" button to ensure that the program has fully processed your input data. Travel time values should be 11 seconds in each direction, and your storage values should be 16 vehicles for through movements and 8 (16) vehicles for right (left) side turning movements.

Figure 49. Example Interchange Saturation Flow Rate Data

If there are any discrepancies between the screen view values shown in this manual and those generated by your computer, try to track down where your data entry differed from that prescribed by this guide. If possible, correct the problem and return to this point.

Remember that if we were analyzing multiple interchanges, we would have provided frontage road information earlier in the data entry and we would now go and enter in all of the information for each successive interchange (i.e., following the same procedure we just used for the first interchange). Since we are evaluating a single interchange, our data entry is now complete.

Select "Run" from the PASSER^{TM} III-98 File Menu Bar to execute the program. If you discover any errors, correct them (to achieve consistency with the input information in this section) and re-run the program.

4.2.2   Examining Evaluation Output

After a successful PASSER^{TM} III-98 run, the System Summary subfolder within the Results folder is displayed. As we were evaluating existing operations (i.e., we did not have the program examine a range of cycle lengths or varying phasing sequence patterns), a single line of output exists displaying the results for the 90 second cycle length, 3-phase, lead-lead case. Note that the overall Total Delay is 38.8 veh-hr/hr, the total stops are 3679 stops/hr, total fuel consumption is 466.4 gal/hr, total cost is 1216.11 $/hr, and there are no movements with a LOS E or F. If you

scroll to the right, you can see individual delays and level of service for each individual movement. Finally, the interior storage ratios are given.

Review the delay and LOS for the individual movements, paying special attention to the interior. These movements have a very good LOS compared to the frontage roads and arterial approaches which operate at LOS C or D. A more balanced timing plan would distribute delays more evenly around the interchange. To provide a better overall view of interchange operation, you can move to the Interchange Level subfolder and select the Average Delay View from the MOE selection pull-down box. Your screen should look like Figure 50.
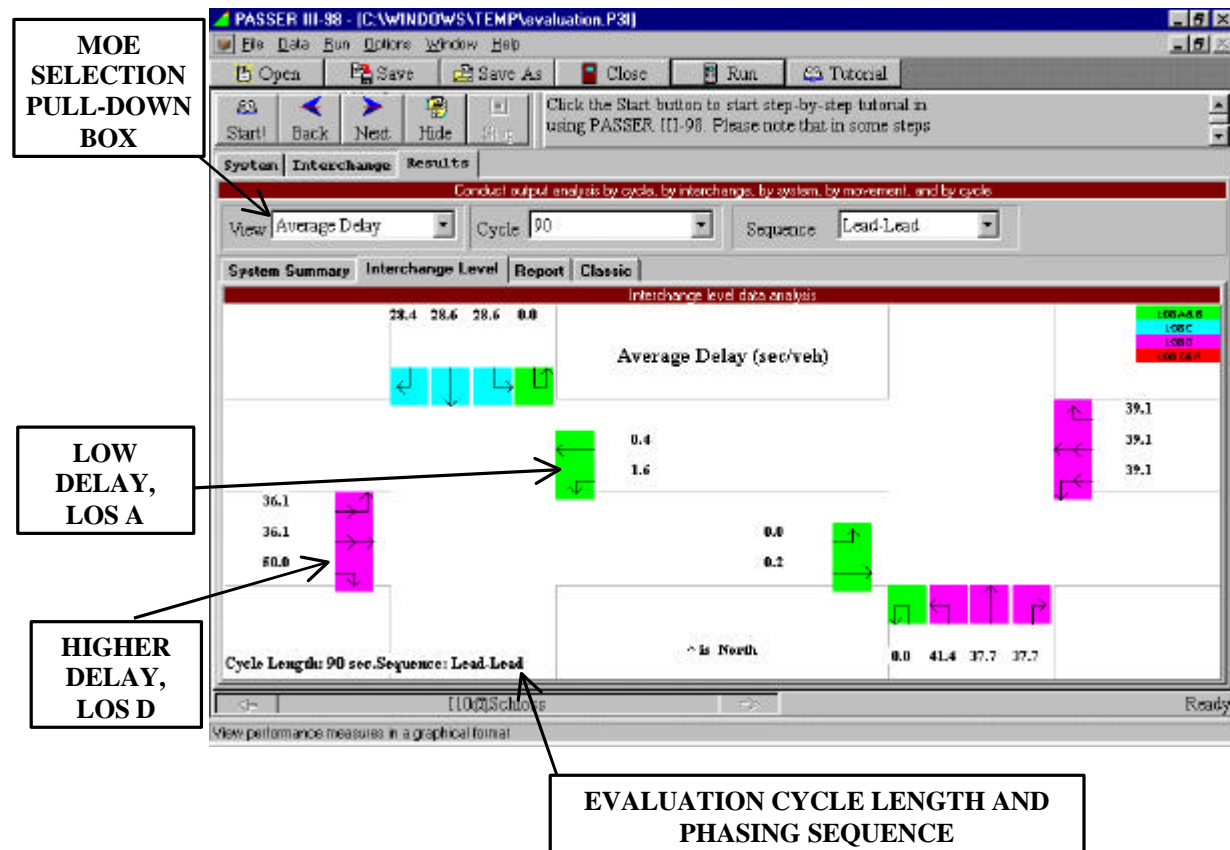

Figure 50. Example Interchange Delay Results

Possible reasons for the problems documented above include the fact that interchange is relatively narrow (243 feet between signals), but was operated with a three-phase timing plan (which tends to be more effective with broader interchanges). It also appears that the green splits were disproportionate to traffic volumes, in that the interior movements had low delays and a good LOS, whereas the exterior movements had higher delays the LOS was worse. The next section addresses optimization strategies that will improve the operation of this interchange.

To generate a report to document this evaluation run, you can go to the Report subfolder and press "Generate RTF Report." A report of approximately 10 pages will be produced and shown

in your document viewer. Also, a graphical animation of interchange operation can be seen under "View Graphical Animation." Finally, the Classic subfolder is available for those who are comfortable with PASSER^{TM} III output that is consistent with previous versions of the program.

4.3   Optimize Interchange Operations

Knowing that we can make some modifications to more equitably balance delays, if not reduce overall delay, we will now attempt a variety of techniques for optimizing interchange operation. The primary methods we have at our disposal to improve interchange performance are modifications to the cycle length, green splits, phasing sequence, and/or interchange geometry.

As we go through the process of identifying possible improvements, remember that some control strategies will not work with some types of field equipment or interchange configurations. In such cases, a near optimal solution may have to be used, or larger scale changes to the controller/display equipment or interchange geometry may be required.

Remember to save your evaluation file so that you can refer to it later and compare it to your optimized solutions. This is easily accomplished by mouse-clicking "Save" (if you have already given your file a name) or "Save As" (where you will be prompted for a file name) from the File Action Bar near the top of the screen. It is important to check the input data for accuracy, and calibrate the input for local conditions before moving on to optimization.

4.3.1   Cycle Length Optimization

An optimal cycle length is one that is long enough to provide acceptable volume-to-capacity ratios, but is simultaneously short enough to minimize overall interchange delay. An effective means for identifying an optimal cycle length is to allow PASSER^{TM} III - 98 to search within a range of reasonable cycle length values. An absolute lower limit on cycle lengths is the sum of minimum phase times at each intersection of the interchange (the longer of the two governs). These minimums will be determined by the longer of pedestrian minimums and vehicular minimums where no pedestrian actuation is provided, and the minimum vehicular times where pedestrian actuation is provided. During periods of high demand throughout the day, the optimal cycle length is likely in excess of that needed for minimum vehicular and/or pedestrian times.

To optimize the cycle length, go to the General subfolder within the System folder and enter the lower and upper limits as well as the increment for the cycle length. Estimates of the lower limit can be based on mathematics that calculate the minimum delay cycle length (*4*). The left and right sides on the interchange may have different minimum cycle length requirements; in most cases, it is best to use the longer of the two as the lower limit. The upper limit is usually within 15 to 20 seconds of the lower limit. If this proves to be an inadequate range, a higher upper limit can be specified (or the overall range raised) in later runs. For our optimization, try 80 to 100 seconds. We will use an increment of 5 seconds to reduce the quantity of output for our example problem, but an increment of 1 second is usually recommended to analyze all cycle lengths within the range you specify. Longer increments, though computationally faster, may not be detailed enough to identify a precise, optimal cycle length.

4.3.2   Phase Split Optimization

Remember that in our previous run we were evaluating current operations and, accordingly, set the minimum phase times for each phase to the actual phase times. Now that we will be optimizing the phase splits, it will be necessary to reduce the minimum times to more realistic values. If our interchange is pedestrian actuated (we will assume that our interchange has push buttons), we need to only ensure that minimum vehicular times are available on each phase (the default minimum time is 10 seconds). For interchanges that are not pedestrian activated, the minimum time should be based on the greater of the minimum vehicular time and the minimum pedestrian time. For both cases, the sum of the minimum times that are entered for each intersection must be less than or equal to the lower cycle length in the cycle length range.

For all cycle lengths, PASSER$^{\text{TM}}$ III-98 will attempt to allocate green times to phases based on an equal-degree-of-saturation approach. In other words, green times are allocated in proportion to the percentage of the intersection's total critical lane volume served by each phase. Thus, the program attempts to provide adequate green time for critical movements (i.e., those with the highest volume to saturation flow ratio). Variability in volume to capacity ratios from movement to movement at a given intersection/interchange, such as we found in our example evaluation, may indicate poor green split allocation.

Go to the Interchange folder, Minimum Phase Time subfolder and change all of the values that we entered during our evaluation to 10 seconds (i.e., we are assuming we have pedestrian push buttons). PASSER$^{\text{TM}}$ III-98 will now optimize green splits within the interchange.

4.3.3   Phasing Sequence Optimization

As we have already learned, the phase strategy used at a diamond interchange depends on the width of the interchange and the turn movement intensity at the interchange. Four-phase with fixed interval transitions tends to work best for closely spaced intersections where heavy interior movements cause storage problems. Three-phase control generally works best for widely spaced interchanges and interchanges with light turning movements (i.e. heavy through movements either on the frontage road or on the arterial). At intermediate spacing, optimal phasing type depends on traffic volume levels and the distribution of turning movements.

The optimum sequence of the interior left-turn phase will depend on whether the predominant interior movements originate from the frontage roads or the cross street arterial. If the left side of the interchange has heavy left turns from the frontage roads, a lead-lag phasing would be preferable. A lead-lead or lag-lag sequence would be more appropriate for heavy interior turns originating from the arterial.

PASSER$^{\text{TM}}$ III-98 is capable of analyzing a variety of phasing combinations for diamond interchanges. In Texas, the choices are often limited to those phasing sequences (i.e., TTI four-phase and Basic three-phase lag-lag) that are specified in an equipment specification for controller devices used at diamond interchanges (*13*). In light of this restriction, let's only optimize these cases. To tell the program to optimize these choices, go to the Phasing subfolder

within the Interchange folder and "check" these two options from the phasing sequence list. Make sure that all other choices are blank and/or unchecked.

4.3.4   Internal Offset Optimization

The progression of interior movements is essential to minimizing vehicular delay at diamond interchanges. The internal offset may be evaluated and optimized based on the phase sequence, volumes, and cycle length. The internal offset is defined as the time from the beginning of the arterial phase on the left side of the interchange (i.e., Phase A or Phase 2) to the end of the frontage road phase on the right side of the interchange (i.e., Phase B or Phase 8). The offset that produces the minimum delay and adequate interior storage ratios is desirable.

To optimize the internal offset, simply ensure that you have not specified an internal offset under the Phasing subfolder of the Interchange folder. In our evaluation, we did specify a 5 second internal offset for the lead-lead phasing sequence. Scroll down to the bottom of the internal offset list box for this sequence and select "None." PASSER^{TM} III-98 will now optimize the offset for the three-phase and four-phase sequences we selected in the previous section.

4.3.5   Left-Turn Treatment Optimization

The interior left-turn movements of the interchange may be protected only (as they were in our evaluation), protected plus permitted, or permitted only. Depending on opposing traffic volumes on the arterial, allowing permissive left-turns may significantly improve the operation of the interior approaches. However, permissive left-turn movements will only improve operations if adequate gaps exist in the opposing traffic stream.

Under the Left Turn Treatment subfolder in the Interchange folder, you have the option of selecting protected only or protected plus permissive left-turn treatments. If you would like to simulate permissive left-turns only (i.e., no Phase "C", or no protected left arrow in the interchange interior), set the minimum phase times for the arterial phase and the frontage road phase so that their sum equals the desired cycle length. Also, set the minimum phase time for the interiors to 0. Note that in order to keep the program from inserting at least some time for the interior left turn phases, you must use a single cycle length (i.e., you cannot specify a range and allow the program to attempt to optimize the cycle length).

In most cases, you will have either protected only or protected plus permissive operation. In our case, we have at least three lanes that oppose our interior left turns on each side. It is common practice that permissive left turns are not allowed across more than two opposing lanes, so we will not change our left turn treatment for the optimization case (i.e., retain protected only value).

4.3.6   Optimizing for Other Improvements

Additional interchange improvements can easily be accounted for in PASSER^{TM} III-98. U-turn lane addition or right-turn bay/lane addition is simulated by simply removing the appropriate volumes from the Interchange folder | Turning Movements subfolder and by removing the movements from the lane movement information in the Interchange folder | Approaches

73

subfolder. Full lane additions are accounted for by simply adding the extra lane into the Interchange folder | Approaches subfolder and allowing the program to recalculate its saturation flow rate values. We will not experiment with any of these enhancements in our current optimization.

4.3.7   Examining Optimization Results

After you have completed making your optimization settings, save the file. Remember that you already saved your evaluation file under the current filename, so you may want to use another descriptive filename for your optimization run. After the file is saved to your new input file, run the program. You should get an output screen that resembles Figure 51.
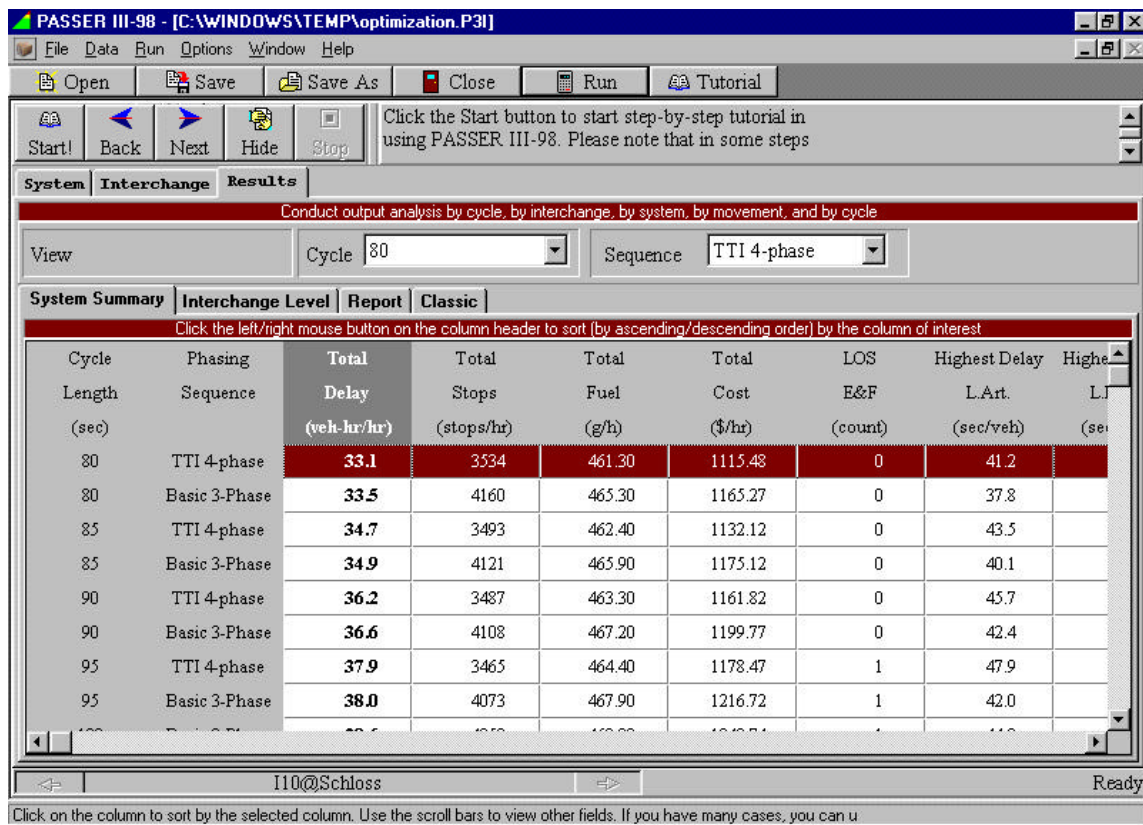
Figure 51. Example Interchange Database of Run Results

From our range of cycle lengths (i.e., 80 to 100 seconds, 5 second increment) and our phasing sequence options (i.e., Basic 3-phase lag-lag and TTI 4-phase), an 80 second cycle length TTI four-phase timing plan produces the least total delay. This optimized delay, 33.1 veh-hr/hr, is reduced from the 38.8 veh-hr/hr calculated during the existing conditions analysis. Thus, by making the cycle length, phasing sequence, phase split, and left turn treatment improvements we included in our optimization run, we were able to reduce interchange delay by 5.7 veh-hr/hr, or about 15 percent.

Before centering on the optimized plan that has the least delay as the "best" solution, remember that an optimal plan also has delay equitably spread around the various movements within the interchange. It also has storage ratios less than 0.8 (ensuring that vehicles do not spill from one interchange intersection into the other) and no LOS E&F movements, if possible. A review of delays, levels of service, and storage ratios (i.e., either by scrolling through the Results folder | System Summary subfolder or viewing Average Delay under the Results folder | Interchange Level subfolder) reveals that our 80 second cycle length TTI four-phase plan meets our most of our acceptance criteria. One exception is that the interior movements remain at a good LOS, while the exterior movements have LOS C or D. If you judge this delay discrepancy as being undesirable, you might consider using the next lowest delay timing plan, the Basic three-phase plan with an 80 second cycle length. Improvements (i.e., lane additions for the left frontage road and/or right arterial) beyond those that we included in our optimization will be necessary in order to improve the operation significantly beyond our optimal values.

As we have evaluated a variety of cycle length, phasing sequence, and phase split options simultaneously, we do not know what impact each individual improvement may have had on our interchange. It is a useful exercise to return to PASSER[TM] III-98 and perform individual optimizations to identify the impacts of each separate improvement. In this manner, it will be possible to determine which improvements contributed the most to our overall, optimized delay savings. Analyzing each improvement separately would also be necessary if you were trying to discover which individual improvements had the greatest potential benefit relative to cost.

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5.0   IMPLEMENTING PASSER^{TM} III-98 OUTPUT

After completing your analysis and producing the desired output, the next step is to take the split (i.e., effective green) time outputs for the output timing plan and convert them into controller phase time inputs. It is emphasized that this step in the process of generating signal timings must be accomplished and/or overseen by a licensed civil engineer with experience in traffic control and traffic engineering principles. Not only do the input controller settings influence the efficient control of the interchange, but they also must include appropriate minimum phase and clearance times for all vehicles and pedestrians using the signalized crossings of the interchange.

To demonstrate the conversion of PASSER^{TM} III-98 output to controller phase inputs, we will use the output from the example problem from section 4.3.7 of this user's guide. Recall that our least delay optimized solution was a TTI four-phase timing plan with an 80-second cycle length. This timing plan is used in this chapter to demonstrate the development of field controller settings for a TTI four-phase timing plan for dual controllers, a single eight-phase controller, and a Texas Diamond Controller. Similarly, we will use the second least delay solution from our example, an 80-second cycle length Basic three-phase timing plan, to demonstrate the development of field controller settings for these same field device configurations.

5.1   Interpretation of Phase Time Output

There are several comprehensive steps to follow during implementation and development of a signal timing plan. The selection of phase times for each movement is just the initial step towards implementation. Phase times are adjusted based on the type of signal hardware and the strategy that will be used at the interchange.

5.1.1 Phase Time Adjustment

There are adjustments that must be made to the phase times in certain situations prior to implementation of a timing plan. Table 7 contains output for the 80-second cycle length, TTI four-phase with fixed interval transitions solution from the example problem. Table 7 shows the phase sequence is a lead-lead pattern, with fixed interval transitions (i.e., also known as the 'internal interval' or 'travel time interval') that form part of the TTI four-phase plan. The fixed interval is 9 seconds, which is two seconds less than the travel time between the two intersections. This interval is the same as the offset and allows for the interior approach to initiate green prior to arrival of vehicles from the exterior arterial approach of the other intersection.

Table 8 displays the Basic three-phase strategy, which is a lag-lag pattern. The Basic three-phase sequence features frontage road phases of equal duration that begin and end together. In this case, there is no offset between the start of the left-side arterial phase and the start of the right-side arterial phase; as just stated, the frontage roads begin and end simultaneously.

Table 7. Example Problem Phase Interval Output – TTI Four-Phase

Movements		Phase Interval	Interval (sec)	Cumulative (sec)
Left Intersection	Right Intersection			
Arterial	Frontage/Ramp		9(Fixed)	9
Arterial	Left Turn		13	22
Frontage/Ramp	Left Turn		31	53
Frontage/Ramp	Arterial		9(Fixed)	62
Left Turn	Arterial		11	73
Left Turn	Frontage/Ramp		7*	80

Note: Offset between start of Left Side Arterial phase and end of Right Side Frontage/Ramp phase is 9 seconds

*Because this split time is short (i.e., less than 10 seconds), this value output by PASSER™ III-98 should be checked to see if it meets minimum requirements (see Sections 1.2.3, 1.2.4 and 1.2.5)

Table 8. Example Problem Phase Interval Output - Basic Three-Phase

Movements		Phase Interval	Interval (sec)	Cumulative (sec)
Left Intersection	Right Intersection			
Arterial	Arterial		22	22
Arterial	Left Turn		1	23
Left Turn	Left Turn		16	39
Frontage/Ramp	Frontage/Ramp		41	80

Note: Offset between start of Left Side Arterial phase and end of Right Side Frontage/Ramp phase is 0 seconds

The phase interval table is an excellent source of information for an overall picture of interchange timing. From such tables, it is possible to calculate interval times for all phases on each side of the interchange. Also, the offset information provided in the table note allows you to observe the impact of the internal offset on the timing relationship between the left and right sides of the interchange.

The phase times that are produced by PASSER™ III-98 require additional reduction prior to input into the controller. The volume to capacity ratios and maximum queue calculated must be checked to evaluate the effectiveness of the timing strategy. The maximum queue should be evaluated against storage distance to determine whether the phase times result in approaches that suffer from queue blocking. Figure 52 displays a flowchart that can be used to track the pre-implementation steps for phase time development.
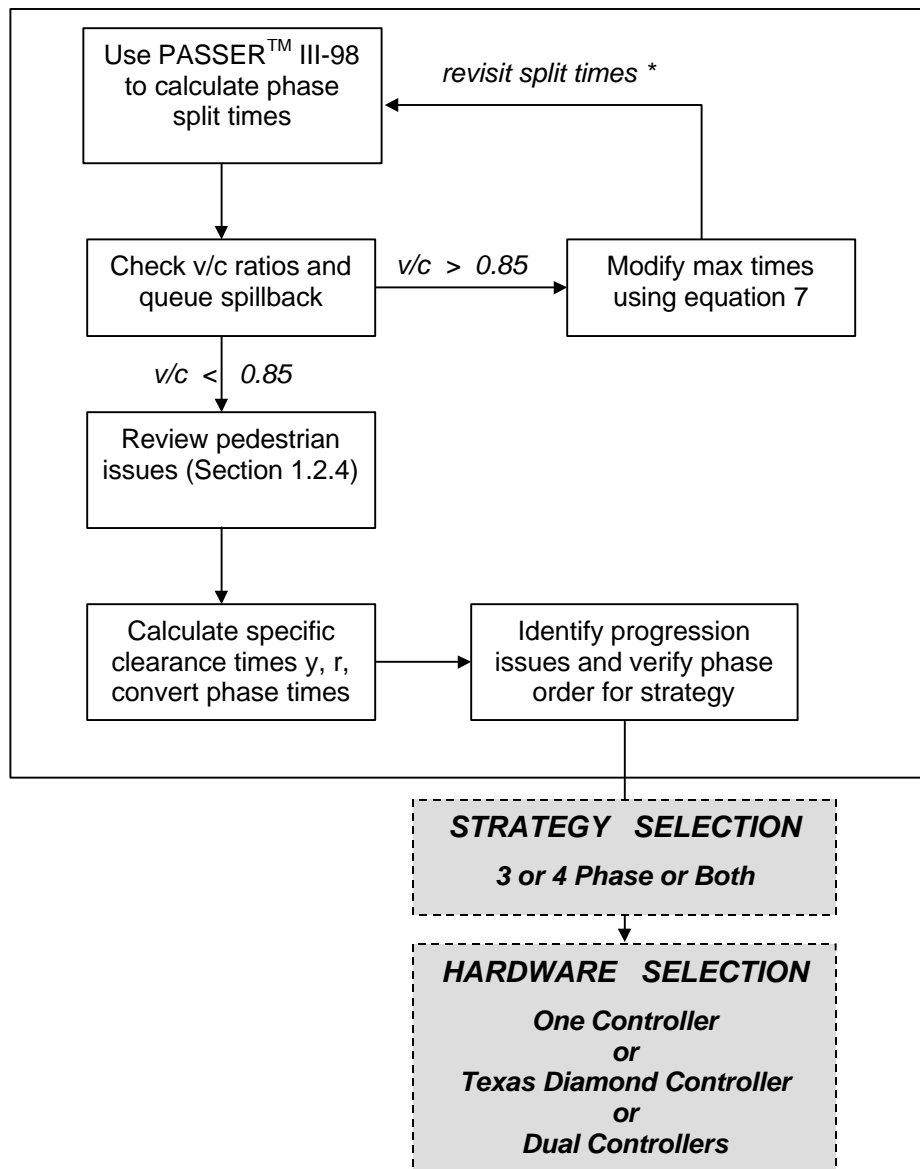
Figure 52. Phase Time Calculation Procedure

5.1.2 Actuated Strategies

The fixed timing plan calculated by PASSER^{TM} III-98 can be modified to create an actuated plan fairly easily, although care must be used and the final plan should be checked by an experienced traffic engineer. A brief description of this process will be discussed here; a more thorough analysis of this implementation was undertaken in TTI Research Report 1164-3 (*10*). The basic premise of this discussion is that actuated controllers require minimum green, vehicle extension, and maximum green times for all interchange phases.

Minimum green times are based on the distance the detectors are setback from the stop bar, unless variable initial is used (see Section 1.2.3). These minimum times normally are set to allow clearance of the queued vehicles between the stop line and the front detector. In the presence of stop line detectors, a smaller minimum green may be set if the detectors are placed in presence mode (i.e., the detector will recognize the end of the queued vehicles). Minimum green times must also consider pedestrian time requirements at each intersection (see Section 1.2.5).

Vehicle extensions, or passage gaps, as they are commonly called, are based on the desired minimum allowable gap that will extend the green interval. These times are based on the speed of the vehicles, detector spacing, and the type of detection. A smaller passage gap will result in more responsive operation at the interchange; however, this may also increase stops.

Maximum green times limit the length of each phase at the interchange. The phase split times can be used as maximum green times for the interchange provided the volume-to-capacity ratios are not greater than 0.85. The phase times can be modified by using the following equation (*11*) for adjustment of phase times that are near capacity ($0.85 < v/c < 0.95$):

$$G_{max} = G + \frac{X^2}{(2 \cdot (1 - X))} \tag{11}$$

where: G_{max} = maximum green (sec);
G = phase time for movement (sec); and
X = v/c ratio for the movement.

It is important to note that increased phase time and cycle length may not necessarily improve operations, in fact it may make queue spillback problems more severe. There are several references that support this, and therefore cycle lengths much greater than 120 seconds should be avoided where possible. Research completed by Herrick and Messer (*12*) provides additional guidance for the timing of oversaturated interchanges.

5.1.2 Other Settings

There are several other settings that apply to actuated controller operation. Volume density functions, detector switching, and other features of modern controllers are used depending on local site characteristics, hardware availability, and other considerations. Other settings, such as yield points and force-off points, allow for semi-actuated operation to maintain coordination. Most modern controller devices automatically compute these settings. For further information on these and other issues about translating PASSER^{TM} III-98 output into controller settings, refer to (*10*).

Section 1.2.5 of this user's guide should be consulted for information about how pedestrian activity will influence timing needs at the interchange. For this example, we will assume that pedestrian push buttons are located at this interchange. Along with these push buttons, we will assume that appropriate minimum pedestrian walk and clearance intervals have been entered into the two controllers in our example. If the push buttons had not been in place, we would have to

examine our geometry and determine (for each phase with an associated pedestrian movement) whether vehicular or pedestrian times govern.

Yellow change and red clearance intervals must be calculated and implemented for each interchange phase. For the examples presented in this guide, we will assume a yellow change interval of four (4) seconds and a red clearance interval of one (1) second for each phase. Please observe that these assumed times are for purposes of this example only. Actual clearance times must be based on site conditions and standard procedures/practices, as presented in Section 1.2.4.

5.2   Hardware Issues for Implementation

Signal controller hardware provided by controller device manufacturers varies widely within the standards established by NEMA (i.e., TS1 and TS2) and by specifications, such as the Type 170 and the Type 2070. The NTCIP will standardize some of the communications within the hardware but the vendor specific features will remain, resulting in a wide variety of steps necessary for implementation. Because of this variety, only a generic description of controller settings will be undertaken in this text.

As mentioned above, the following sections will review the implementation of PASSER^{TM} III-98 timing plans into various controller configurations. The most common of which is the Texas Diamond mode, which provides featured default settings that simplify implementation to a certain extent. The dual controller configuration is used in places where signals are widely spaced and one controller was not designed to handle the traffic control. Table 9 refers to the functionality of each of the controller configurations.

Table 9. Functionality of Controller Configurations

	One Controller (8ϕ)		Two Controllers		Texas Diamond Controller	
	Pretimed	Actuated	Pretimed	Actuated	Pretimed	Actuated
Isolated (Fully Actuated)						
Cycle Length	Fixed	Variable	Fixed	Variable	Fixed	Variable
Three Phase	Yes	Yes	No*	No**	Basic Only	Basic Only
Four Phase	Yes	Yes	No*	No**	Yes	Yes
Both (3ϕ & 4ϕ)	No	No	No	No	Yes	Yes
Internal Coordination	Yes	Yes	No*	No**	Yes	Yes
Part of A Coordinated Arterial						
Cycle Length	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Three Phase	Yes	Yes	Yes	No***	Yes	Yes
Four Phase	Yes	Yes	Yes	No***	Yes	Yes
Both (3ϕ & 4ϕ)	No	No	No	No	Yes	Yes

* Due to drifting of the clock
** Due to a lack of a relationship between the two fully actuated controllers
*** Due to a lack of a relationship between the actuated phases in the two semi-actuated controllers

5.3   Development of Timing for Dual Controllers

Originally, two traffic signal controllers in two separate cabinets controlled the traffic signals at diamond interchanges. These systems were established as pretimed controllers that were electromechanical devices that used from two to eight phases to control the intersections of the interchange. It is possible to implement all PASSER^{TM} III-98 output timing plans using dual controllers in either pretimed or actuated mode with the exception of the TTI four-phase sequence, which can only be implemented in a pretimed (i.e., not actuated) manner with dual controllers. For a dual controller setup to work properly, the individual controllers managing each side of the interchange must be interconnected. Interconnection can be by either a set time point (fixed cycle length, time based coordination) or some type of physical connection (i.e., via twisted pair cable, fiber optic cable, radio, etc.). This connection ensures that the intersections remain in coordination with respect to one another. The examples discussed in this dual-controller section will utilize a fixed cycle length for coordination. It should be noted for completeness that it is possible in some manufacturer's controllers to operate a single controller, but allow each intersection to operate either fully actuated or with some form of coordination.

Be aware that coordination may get out of step, or fall out of synchronization, during cycle-by-cycle resynchronization, during a transition from one timing plan to another, during some pedestrian service calls, and during preemption. As the controllers attempt to regain coordination, shorter or longer phase times may be displayed for some phases, causing driver expectancy issues. Driver expectancy is mainly an issue for closely spaced intersections where signal heads may have visibility issues and drivers "expect" a certain operation/timing. This effect is intensified (and some additional controller limitations may impact operations) when the dual controllers managing the diamond are coordinated with other intersection and/or interchange controllers. All transition and coordination impacts must be thoroughly investigated by the traffic engineer developing the plan.
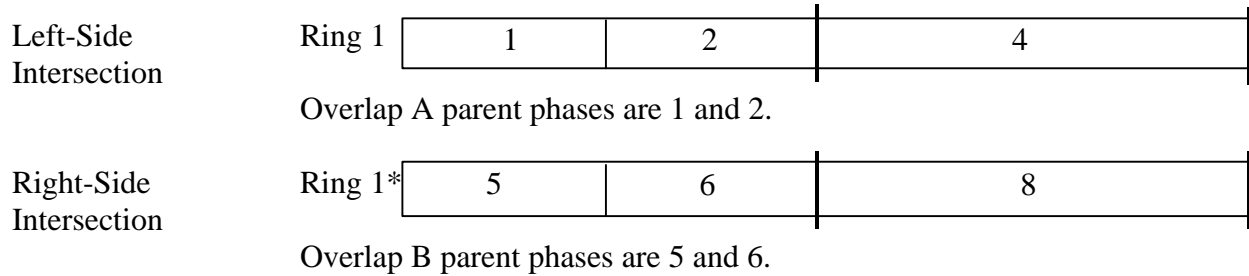
5.3.1   Dual Controller Timing for TTI Four-Phase Operation

TTI four-phase implemented on two controllers results in a fixed timing plan and a constant cycle length. Section 5.2 of the PASSER^{TM} III-98 RTF output report for our example problem contains split (i.e. green + clearance) times for each phase at each intersection of the interchange. This information is combined with the phase interval and offset information found in Table 7 (i.e., RTF report section 5.1) to produce the correct phasing for the interchange. Table 10 displays the split times calculated by PASSER III-98 for our optimized plan. These values must be converted to phase interval (i.e., green, yellow, and all red clearance) times.

Table 10. Movement Timing for Dual Controllers – TTI Four-Phase

Movement	Left Intersection			Right Intersection		
	Left Turn	Arterial	Frontage/Ramp	Left Turn	Arterial	Frontage/Ramp
Total (sec)	18	22	40	44	20	16

The ring structure and overlap definition for each of the two controllers is shown below in Figure 53. The ring structure shown uses the phase numbering scheme shown in Figure 2.

Left-Side Intersection	Ring 1	1	2	4

Overlap A parent phases are 1 and 2.

Right-Side Intersection	Ring 1*	5	6	8

Overlap B parent phases are 5 and 6.

* For convenience, we are using our standard phase numbering scheme (see Figure 2).

Figure 53. Ring Structure for Dual Controller Operation – TTI Four-Phase

Table 11 contains the output for our example interchange, mathematically converted into phase time recommendations for input into the two controllers that govern our interchange.

Table 11. Dual Controller Phasing for Example Interchange - TTI Four-Phase

Intersection	Left Side Controller				Right Side Controller			
Phase	1	2	4	*OLA**	*OLB**	5	6	8
Split Time	18	22	40	*40*	*64*	44	20	16
Phase Green Time	13	17	35	*35*	*59*	39	15	11
Yellow Clearance	4	4	4	*4*	*4*	4	4	4
All Red Clearance	1	1	1	*1*	*1*	1	1	1

* Split times for OLA and OLB are not directly entered into the controller; they are derived by adding the phase durations of their respective parent phases (OLA = phases 1 and 2; OLB = phases 5 and 6).

Note that dual controllers using a TTI four-phase sequence can operate in pretimed mode only. This is the primary limitation of dual controllers for TTI four-phase control. This limitation is due to the fact that coordination is designed to create only one synchronization point in the cycle. A TTI four-phase plan requires two coordination points to correspond to the starting points of its two, fixed time interval transitions (which are also called the 'transition intervals', 'travel time intervals', or 'internal intervals'). This limitation does not impact dual controllers operating in pretimed mode, since coordination exists between the (two) controllers and all phases programmed in each controller are of a fixed duration. As with all timing plans, it is necessary for the traffic engineer and technician to examine how their controller equipment operates during synchronization (i.e., after railroad preemption, or transitioning from one timing plan to another) to ensure appropriate and safe phase displays.

For the TTI four-phase solution, phase 2 is the coordinated phase for the left intersection, and phase 5 is the coordinated phase at the right intersection. It is necessary to define phase 2 (phase 5) as the coordinated phases for the left (right) side intersections so that the controllers are able to maintain the time relationship, or "sync," between the two intersections.

The final consideration for dual controller operation is establishing the time relationship, or offset, between the timing cycles at each intersection. In a TTI four-phase sequence, the offset specified as the programmed, relative offset between the dual controllers is the same value as the fixed time interval value output by PASSER^{TM} III-98. We will begin by diagramming the phases at each intersection in the order in which they appear in our phase interval output table (Table 11). Note that in Figure 54, time increases from the bottom of the page, which is the opposite of how the phase information is displayed in Table 11.
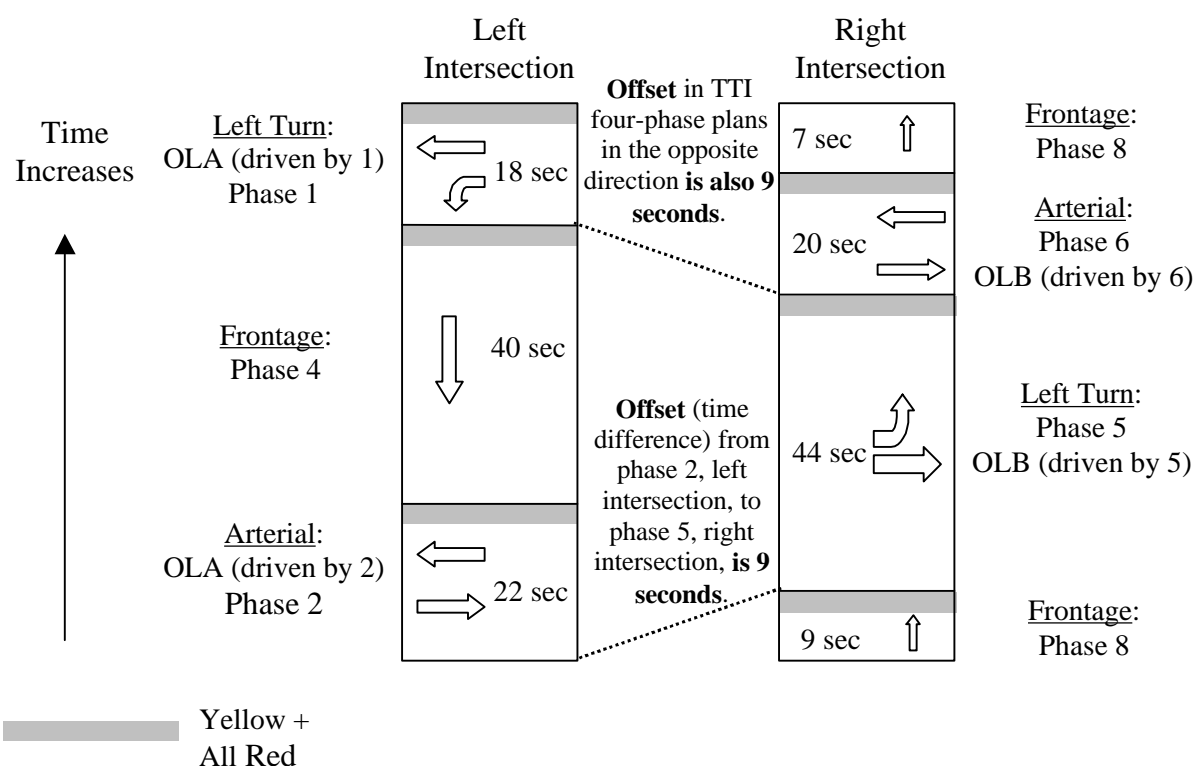
Figure 54. TTI-Four Phase Dual Controller Offset Development

Again, notice from Figure 54 that the offset, or time difference, between phase 2 at the left intersection and phase 5 at the right intersection is 9 seconds. Recall the PASSER^{TM} III-98 definition of internal offset as the time difference between the start of the left side arterial phase and the end of the right side frontage frontage/ramp phase. In this instance, the offset in time we need between the coordination phases at our two controllers is the same as the "internal offset" necessary to produce the TTI four-phase sequence at our interchange. Notice also that the offset between the exterior and interior through phases in the opposite direction is also 9 seconds.

5.3.2   Dual Controller Timing for Basic Three-Phase Operation

The presence of dual controllers at a field site allows a great deal of flexibility in implementing three-phase timing plans. However, a Basic three-phase plan is, by definition, restricted to having the frontage road phases start and end at the same time. Basic three-phase is more

common in single controller operations, due to the nature of ring and barrier rules. It has the advantage of providing more defined relationships at the two intersections of the interchange, but does limit flexibility to some degree. Basic three-phase implementation on dual controllers is discussed in this section; for more information on utilizing dual controllers for more flexible three-phase timing plan implementation, see section 5.3.3.
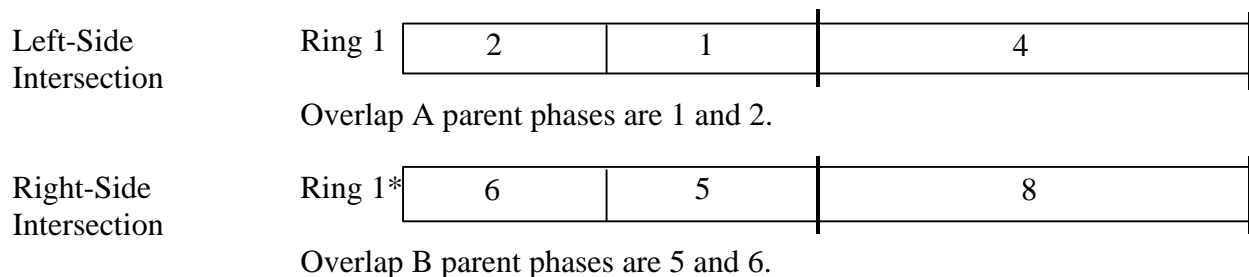
As with a TTI four-phase output, the PASSER™ III-98 RTF report for a Basic three-phase timing sequence contains split (i.e., green+clearance) times for each movement on each side of the interchange. This information is combined with the phase interval and offset information found in Table 8 (i.e., RTF report section 5.1) to produce the correct phasing for the interchange. Table 12 contains the split times for our optimized plan for each primary movement. We must now convert these times to phase interval (i.e., green, yellow, and all red clearance) times in our dual controller scenario.

Table 12. Movement Timing for Dual Controllers – Basic Three-Phase

Movement	Left Intersection			Right Intersection		
	Left Turn	**Arterial**	**Frontage/Ramp**	**Left Turn**	**Arterial**	**Frontage/Ramp**
Total (sec)	16	23	41	17	22	41

Phase 2 is the coordinated phase for the left intersection, and phase 6 is the coordinated phase at the right intersection. It is necessary to define phase 2 (phase 6) as the coordinated phases for the left (right) side intersections so that the controllers are able to maintain the time relationship, or "sync," between the two intersections. By defining phase 6 as the coordinated phase for the right side intersection, we know that for a Basic three-phase (i.e., lag-lag) phase sequence, the offset is zero (0) (i.e., the frontage road phases end together, so the arterials begin together).

The ring structure and overlap definition for each of the two controllers is shown in Figure 55. With a ring structure in hand, we can now begin to translate our split time output into phase timing data that can be input into the controller.

Left-Side Intersection   Ring 1 | 2 | 1 | 4 |

Overlap A parent phases are 1 and 2.

Right-Side Intersection   Ring 1* | 6 | 5 | 8 |

Overlap B parent phases are 5 and 6.

* For convenience, we are using our standard phase numbering scheme (see Figure 2).

Figure 55. Ring Structure for Dual Controller Operation – Basic Three-Phase

Table 13 contains the phase time recommendations for input into the two controllers that govern our interchange. It is important to note that, by definition, a Basic three-phase plan has frontage road phases (on each side) that begin and end together. In dual controller operation, this can only be guaranteed if the two controllers are operating in a coordinated mode. In a dual controller solution the three-phase strategy maintains two fixed points about the phase pattern. The fixed cycle length of a dual controller scenario is one point which constrains the strategy. The second fixed portion of the strategy is the defined offset. The timings given for a Basic three-phase plan can be entered into dual controllers operating in actuated mode, but the ramifications of phases ending early and starting early (with respect to the same timings in a coordinated mode) must be fully investigated and approved by the traffic engineer. As with all timing plans, it is necessary for the traffic engineer to examine how their controller equipment operates when resynchronizing (i.e., after railroad preemption, some pedestrian activity, or transitioning from one timing plan to another) to ensure appropriate and safe phase displays.

Table 13. Dual Controller Phasing for Example Interchange - Basic Three-Phase

Intersection	Left Side Controller				Right Side Controller			
Phase	1	2	4	*OLA**	*OLB**	5	6	8
Split Time	16	23	41	*39*	*39*	17	22	41
Phase Green Time	11	18	36	*34*	*34*	12	17	36
Yellow Clearance	4	4	4	*4*	*4*	4	4	4
All Red Clearance	1	1	1	*1*	*1*	1	1	1

* Split times for OLA and OLB are not directly entered into the controller; they are derived by adding the phase durations of their respective parent phases (OLA = phases 1 and 2; OLB = phases 5 and 6).

These phase times are most appropriate for dual controllers operating in pretimed mode. For dual controllers operating in semi-actuated (coordinated) mode, the phase green time (effective green minus clearances) that is shown in Table 13 can be interpreted as the maximum green time for all phases whose v/c ratio is less than or equal to 0.85. The methodology discussed in Section 5.1 can be used to adjust these split time to suit an oversaturated interchange.

Note that the use of this equation to increase the maximum green time will also increase the cycle length. If the cycle length increases for one of the two intersections of the interchange, you must also increase the cycle length for the other intersection. If any phases have a v/c ratio greater than 0.95, the capacity of the interchange may be inadequate. Steps should be taken to re-analyze the intersection so that all phases are adequate, and so that no phase or group of phases has a disproportionately large v/c burden.

5.3.3   Dual Controller Timing for Generic Three-Phase Operation

A more generic three-phase solution does not restrict the timing of the frontage road movements, allowing the frontage roads to operate simultaneously with other movements at the other intersection.

As with TTI four-phase output, the PASSER^{TM} III-98 RTF report for a generic three-phase timing sequence contains split (i.e., green+clearance) times for each movement on each side of the interchange. This information is combined with the phase interval and offset information

found in Table 7 (i.e., RTF report section 5.1) to produce the correct phasing for the interchange. Table 14 contains the split times for our optimized plan for each primary movement. We must now convert these times to phase interval (i.e., green, yellow, and all red clearance) times in our dual controller scenario.

Table 14. Movement Timing for Dual Controllers – Generic Three-Phase

Movement	Left Intersection			Right Intersection		
	Left Turn	Arterial	Frontage/Ramp	Left Turn	Arterial	Frontage/Ramp
Total (sec)	16	23	41	17	22	41

Phase 2 is the coordinated phase for the left intersection, and phase 6 is the coordinated phase at the right intersection. It is necessary to define phase 2 (phase 6) as the coordinated phase for the left (right) side intersection so that the controllers are able to maintain the time relationship, or "sync," between the two intersections.

The ring structure and overlap definition for each of the two controllers is shown in Figure 56. With a ring structure in hand, we can now begin to translate our split time output into phase timing data that can be input into the controller.

Left-Side Intersection	Ring 1	2	1	4

Overlap A parent phases are 1 and 2.

Right-Side Intersection	Ring 1*	6	5	8

Overlap B parent phases are 5 and 6.

* For convenience, we are using our standard phase numbering scheme (see Figure 2).

Figure 56. Ring Structure for Controller Operation – Generic Three-Phase

Table 15 contains the phase time recommendations for input into the two controllers that govern the interchange. In a dual controller solution the 3-phase strategy maintains two fixed points about the phase pattern. The fixed cycle length of a dual controller scenario is one point which constrains the strategy. The second fixed portion of the strategy is the defined offset. The distance between the intersections is a concern when evaluating a generic three-phase solution because of the driver expectancy issue, especially with closely spaced intersections. The timings given for a three-phase plan can be entered into dual controllers operating in actuated mode, but the ramifications of phases ending early and starting early (with respect to the same timings in a pretimed mode) must be fully investigated and approved by the traffic engineer. As with all timing plans, it is necessary for the traffic engineer to examine how their controller equipment operates when resynchronizing (i.e., after railroad preemption, some pedestrian activity if adequate time to maintain coordination is not provided, or transitioning from one timing plan to another) to ensure appropriate and safe phase displays.

Table 15. Dual Controller Phasing for Example Interchange - Generic Three-Phase

Intersection	Left Side Controller				Right Side Controller			
Phase	1	2	4	*OLA**	*OLB**	5	6	8
Split Time	16	23	41	*39*	*39*	17	22	41
Phase Green Time	11	18	36	*34*	*34*	12	17	36
Yellow Clearance	4	4	4	*4*	*4*	4	4	4
All Red Clearance	1	1	1	*1*	*1*	1	1	1

* Split times for OLA and OLB are not directly entered into the controller; they are derived by adding the phase durations of their respective parent phases (OLA = phases 1 and 2; OLB = phases 5 and 6).

These phase times are most appropriate for dual controllers operating in pretimed mode. For dual controllers operating in semi-actuated (coordinated) mode, the phase green time (effective green minus clearances) that are shown in Table 15 can be interpreted as the maximum green time for all phases whose v/c ratio is less than or equal to 0.85. The methodology discussed in Section 5.1 can be used to adjust these split time to suit an oversaturated interchange.

Note that the use of this equation to increase the maximum green time will also increase the cycle length. If the cycle length increases for one of the two intersections of the interchange, you must also increase the cycle length for the other intersection. If any phases have a v/c ratio greater than 0.95, the capacity of the interchange may be inadequate. Steps should be taken to re-analyze the intersection so that all phases are adequate, and so that no phase or group of phases has a disproportionately large v/c burden.

5.4   Development of Timing for Single Controllers

The following section will describe a means of translating PASSER^{TM} III-98 TTI four-phase and Basic three-phase output into controller settings that can be accepted by a standard NEMA TS-1 controller device.

5.4.1   Single Controller Timing for TTI Four-Phase Operation

Table 16 contains the PASSER^{TM} III-98 RTF report section 5.3 (i.e., single controller) output for our example problem, with an 80 second cycle length and a TTI four-phase plan. Contained within Table 16 are the phase movement numbers and fixed interval transition information for a diamond interchange operated by a single controller.

Table 16. Phase Timing for a Single Controller – TTI Four-Phase

Phase/Overlap	φ1	φ 2	φ 4	φ 5	φ 6	φ 8	Overlap* OVL 2+8*	Overlap* OVL 4+6*
Total (sec)	18	22	31	44	20	7**	9	9

* These output sections from PASSER^{TM} III-98 refer to fixed interval transitions.
** Because this split time is short (i.e., less than 10 seconds), this value output by PASSER^{TM} III-98 should be checked to see if it meets minimum requirements (see Sections 1.2.3, 1.2.4 and 1.2.5)

Table 16 is interpreted using Figure 57, which shows a unique intersection phasing nomenclature imposed on a diamond interchange. Special modifications had to be made in order to use the standard phasing scheme for single controller TTI four-phase implementation. Notice from Figure 57 that phases 3 and 7, which normally would be reserved for five-legged intersection approaches, are used to supplement phasing on the frontage roads. In essence, these phases will be used as fixed interval transitions (i.e., travel time interval, or transition interval, or internal interval) that form the end of the frontage road phases at each intersection. That is, the last few seconds (9 seconds in our case) of phase 4 (phase 8) for the frontage road is timed within the controller using the phase 3 (phase 7) timer for the left (right) side intersection.

The ring structure that is used along with TTI four-phase operation in a single (NEMA standard) eight phase controller is shown in Figure 58. Notice that our fixed time phases, phase 3 and 7, are both located immediately to the right of a barrier. This qualification is necessary to ensure that the timing between the two intersections is accurate. Such a restriction is possible because the minimum and maximum times of phase 3 (or phase 7) are the same, and the fact that phase 3 (phase 7) is to the right of the barrier means that it will begin at the same time as the arterial phase. Accompanying the ring structure is the fact that the parent phases for overlap A (OLA) are phases 1 and 2, and the parent phases for overlap B (OLB) are phases 5 and 6. Also, the parent phases for overlap C (OLC) are phases 3 and 4, and the parent phases for overlap D (OLD) are phases 7 and 8. With a ring structure and overlap definitions in hand, we can now distribute the PASSER^{TM} III-98 split time output into controller phase timing data.

Table 17 contains the output for our example interchange, mathematically converted into phase time recommendations for input into the controller. In maintaining PASSER^{TM} III-98 phase designations, we have referred to the fixed interval transitions as simultaneous phases (i.e., OVL 2+8 means that both phases 2 and 8 are active; OVL 4+6 means that both phases 4 and 6 are active). In this instance (and using Figure 57), OVL 2+8 refers to phase 7, and OVL 4+6 refers to phase 3. Note that Table 17 contains clearance times for phases 4 and 8, but during these intervals the overlaps (i.e., OLC and OLD) keep the phase displays for the frontage roads green. Observe that phases 4 and 8 are actually only a portion of the frontage road phase, with phase 3 forming the latter part of phase 4, and phase 7 forming the latter portion of phase 8. The total clearance time we are using (4 + 1 = 5 seconds) is less than the duration of phases 3 or 7, so no portion of the clearance is a part of phases 4 or 8.
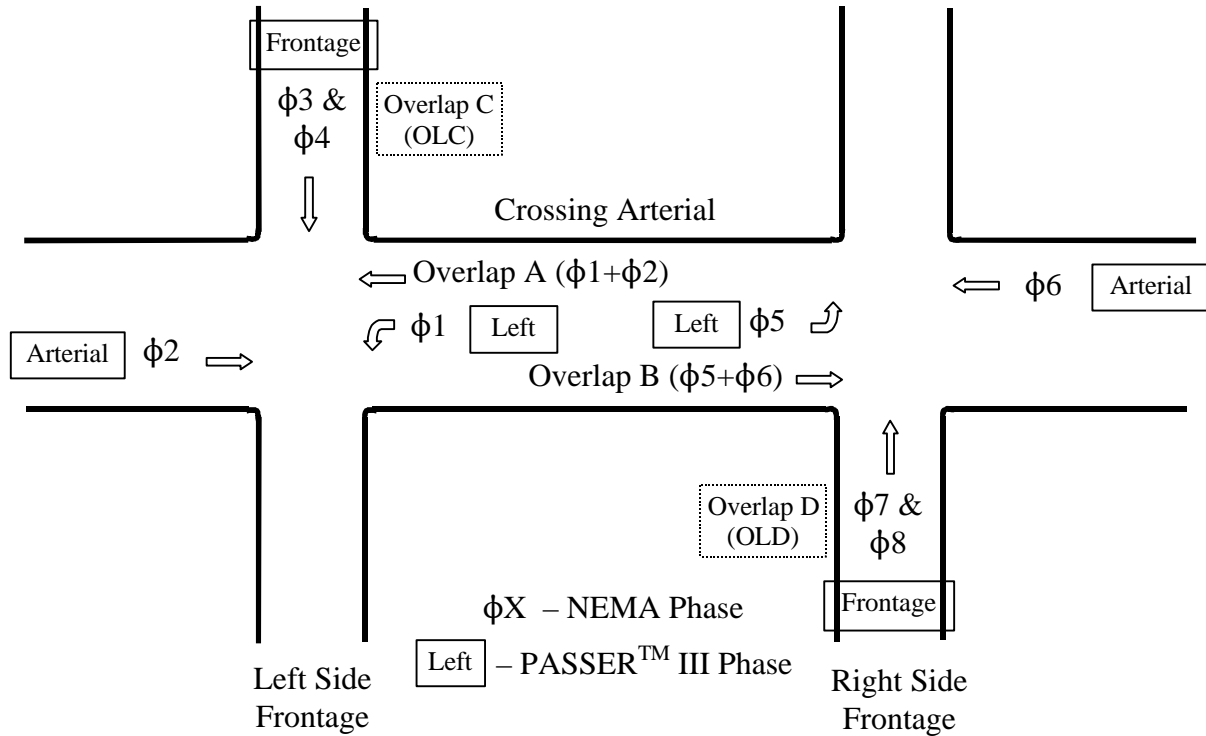
Figure 57. Phasing for a Diamond Interchange - Single Controller, TTI Four-Phase

Eight-Phase
Controller

Ring 1	3*		1		2		4	
Ring 2	6			8		7*	5	

Phases 3 and 7 are fixed interval transitions

Note: OLA = phases 1 + 2; OLB = phases 5 + 6; OLC = phases 3 + 4; OLD = phases 7 + 8

Figure 58. Ring Structure for Single Controller Operation - TTI Four-Phase

Table 17. Single Controller Phasing for Example Interchange - TTI Four-Phase

Intersection	Interchange Controller							
Phase	1	2	4	5	6	8	OVL** 2+8 (phase 7)	OVL** 4+6 (phase 3)
Split Time	18	22	31	44	20	7	9	9
Phase Green Time	13	17	26	39	15	2	4	4
Yellow Clearance	4	4	4*	4	4	4*	4	4
All Red Clearance	1	1	1*	1	1	1*	1	1

Appropriate clearance interval times are entered for phases 4 and 8, and these intervals are timed within the controller, but clearances do not appear since the overlaps (i.e., OLC and OLD) keep the frontage road indications green in the transitions [i.e., phase 4 to phase 3 (OVL 4+6), and phase 8 to phase 7 (OVL 2+8)].
** Refers to fixed interval transitions

5.4.2   Single Controller Timing for Basic Three-Phase Operation

Table 18 contains the PASSER^{TM} III-98 RTF output for the Basic three-phase solution from our example problem.   Within this table are the phase numbers and overlap information for a diamond interchange operating a Basic three-phase plan using a single controller. Internal to the program, the frontage road phase lengths are constrained to equal one another (i.e., as per the definition of Basic three-phase operation). The ring structure internal to the controller will maintain the fixed relationship between the frontage roads (frontage roads begin and end together).

Table 18. Phase Timing for a Single Controller – Basic Three-Phase

Phase/Overlap	↰ φ1	→ φ 2	↓ φ 4	↱ φ 5	← φ 6	↑ φ 8	Overlap* OVL* -	Overlap* OVL* -
Total (sec)	16	23	41	17	22	41	-	-

* Refer to fixed interval transitions, which are not found in a Basic three-phase plan

The ring structure for the controller that produces our Basic three-phase plan is shown below in Figure 59.

Interchange Controller	Ring 1	2	1	4
	Ring 2	6	5	8

Note: OLA = phases 1+2; OLB = phases 5+6

Figure 59. Controller Ring Structure for Single Controller Operation

With a ring structure and overlap definitions in hand, we can now begin to translate our split time output from PASSER^{TM} III-98 into phase timing data that can be input into the controller.

Table 19 contains the output for our example interchange, mathematically converted into phase time recommendations for input into the controller. Notice that the OVL (overlap) entries are blank. In single controller operation, they are used only for a TTI four-phase plan.

Table 19. Single Controller Phasing for Example Interchange - Basic Three-Phase

Intersection	Interchange Controller							
Phase	1	2	4	5	6	8	OVL*	OVL*
Split Time	16	23	41	17	22	41	-	-
Phase Green Time	11	18	36	12	17	36	-	-
Yellow Clearance	4	4	4	4	4	4	-	-
All Red Clearance	1	1	1	1	1	1	-	-

* Refer to fixed interval transitions, which are not found in a Basic three-phase plan

These phase times are most appropriate for a controller operating in pretimed mode. For a single controller operating in actuated mode, the phase green time (split minus clearances) that is

shown in Table 19 can be interpreted as the maximum green time for all phases whose v/c ratio is less than or equal to 0.85.

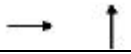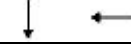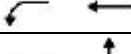## 5.5   Development of Timing for Texas Diamond Controllers

As mentioned previously in this user's guide, the Texas Department of Transportation has developed a specification for the Texas Diamond Controller (*13*). A controller meeting this specification is capable of directly receiving PASSER^{TM} III-98 phase settings for both the Basic three-phase and the TTI four-phase timing plans. If timings are to be directly and easily input into a Texas Diamond Controller, they should be one of these phase sequence options.

5.5.1   Texas Diamond Controller Timing for TTI Four-Phase Operation

The manufacturers that have built controllers that comply with the Texas Diamond specification have basically created a modified version of their normal controller software, with added features necessary for entering and monitoring the status of TTI four-phase and Basic three-phase sequence features. However, in order to properly enter in timings to these devices, it is necessary that the traffic engineer and signal technician be familiar with all of the features and details of the specification, and that they are aware of how the specification was implemented by each manufacturer of specification-compliant devices.

The output given by PASSER^{TM} III-98 that is intended to be input into Texas Diamond Controllers is the same RTF report phase interval output table (Table 7) and phase timing table (Table 16) given for single controllers. However, the Texas Diamond Controller specification has given unique names to each timing interval in the phase interval table (see Table 20).

**Table 20. TTI Four-Phase Interval Names for Texas Diamond Controller**

Movements		Phase Interval	Texas Diamond Controller Interval Name
Left Intersection	Right Intersection		
Arterial	Frontage/Ramp	→ ↑	Transition Interval 18 to 25
Arterial	Left Turn	→ ⤷	Interval 25
Frontage/Ramp	Left Turn	↓ ⤷	Interval 45
Frontage/Ramp	Arterial	↓ ←	Transition Interval 45 to 16
Left Turn	Arterial	⤶ ←	Interval 16
Left Turn	Frontage/Ramp	⤶ ↑	Interval 18

Each interval shown in Table 20 derives its name from the active (NEMA) phase numbers (or the transition between intervals) from Figure 2 (not Figure 57) during each of the six time intervals within the plan. Note that if the controller is operated in actuated mode, it is possible to skip some phases on each side of the interchange, and use a time period during which both interior

left turns are active as a clearance interval. This clearance interval is also known by its phase numbers, and it is known as Interval 15.

It remains necessary to convert the phase interval information into a phase numbering scheme and ring structure that will produce the desired timing solution. Table 21 (copy of Table 16) contains the phase timing for our single controller TTI four-phase solution. The two overlap entries, OVL 2+8 and OVL 4+6, should be interpreted by the names they are given in the specification. OVL 2+8 is the same as Transition Interval 18 to 25, and OVL 4+6 is the same as Transition Interval 45 to 16.

Table 21. Phase Timing for a Texas Diamond Controller - TTI Four-Phase

Phase/Overlap	↰ φ1	→ φ 2	↓ φ 4	↱ φ 5	← φ 6	↑ φ 8	Overlap* OVL 2+8*	Overlap* OVL 4+6*
Total (sec)	18	22	31	44	20	7	9	9

* These output sections from PASSER^{TM} III-98 refer to fixed interval transitions.
** Because this split time is short (i.e., less than 10 seconds), this value output by PASSER^{TM} III-98 should be checked to see if it meets minimum requirements (see Sections 1.2.3, 1.2.4 and 1.2.5)

Unfortunately, manufacturers have chosen different methods of internally organizing the phasing logic systems that produce the TTI four-phase timing plan. Thus, it is necessary to consult the user's manual to correctly configure the ring structure required to generate your four-phase plan.

Once a traffic engineer and/or signal technician has correctly configured the controller ring structure and other internal settings, the next step is to convert the split times in Table 21 into phase time inputs for the controller. A critical and essential step during this procedure is the calculation of appropriate yellow clearance and all red clearance interval times for each phase.

Table 22 (copy of Table 17) contains the output for our example interchange, mathematically converted into phase time recommendations for input into the controller that governs our interchange. In maintaining PASSER^{TM} III-98 phase designations, we have not included the names Transition Interval 18 to 25 and Transition Interval 45 to 16; rather, we have retained the names OVL 2+8 and OVL 4+6, respectively. The reason for this detail is that phases 4 and 8 are actually only a portion of the frontage road phase, with OVL 4+6 forming the latter part of phase 4, and OVL 2+8 forming the latter portion of phase 8. The total clearance time we are using (4 + 1 = 5 seconds) is less than the duration of OVL 4+6 or OVL 2+8, so no portion of the clearance is a part of phases 4 or 8.

Table 22. Texas Diamond Controller Phasing for Example Interchange – TTI Four-Phase

Intersection	Interchange Controller							
Phase	1	2	4	5	6	8	OVL** 2+8 (Transition Interval 18 to 25)	OVL** 4+6 (Transition Interval 45 to 16)
Split Time	18	22	31	44	20	7	9	9
Phase Green Time	13	17	26	39	15	2	4	4
Yellow Clearance	4	4	4*	4	4	4*	4	4
All Red Clearance	1	1	1*	1	1	1*	1	1

Appropriate clearance interval times are entered for phases 4 and 8, and these intervals are timed within the controller, but clearances do not appear since overlap structure keeps the frontage road indications green in the transitions (i.e., phase 4 to OVL 4+6, and phase 8 to OVL 2+8).
*** Refers to fixed interval transitions*

These phase times (except for OVL 4+6 and OVL 2+8, which are always fixed intervals) are most appropriate for a controller operating in pretimed mode. For a single controller operating in actuated mode, the phase green time (split minus clearances) that is shown in Table 22 can be interpreted as the maximum green time for all phases whose v/c ratio is less than or equal to 0.85

5.5.2   Texas Diamond Controller Timing for Basic Three-Phase Operation

Entering timings into a Texas Diamond Controller operating in Basic three-phase mode is functionally the same as entering timings into a standard NEMA eight phase controller. The only difference is one of terminology; the Texas Diamond Controller gives unique names to each phase interval in a Basic three-phase plan. The interval names are derived from the active NEMA phases on each side of the interchange during each interval. Table 23 shows the interval names for our example problem Basic three-phase solution, which was given in Table 8.

Table 23. Basic Three-Phase Interval Names for Texas Diamond Controller

Movements		Phase Interval	Texas Diamond Controller Interval Name
Left Intersection	Right Intersection		
Arterial	Arterial	→ ←	Interval 26
Arterial	Left Turn	→ ↱	Interval 25
Left Turn	Left Turn	↵ ↱	Interval 15
Frontage/Ramp	Frontage/Ramp	↓ ↑	Interval 48
And included for clarification, though not present in our example problem:			
Left Turn	Arterial	↵ ←	Interval 16

Note that the interval names shown for this example are based on the active NEMA phase numbers. Other outputs will likely have different intervals (and thus, different interval names) simply because the phases contained within them will have different durations. The Basic three-phase sequence (i.e., internal left turns lag opposing through phases on each side) is the same.

All of the features of this timing plan, beyond the terminology associated with phase interval naming and reference, are the same as the data entry for a standard NEMA controller. Remember that pedestrian and vehicle minimum times and clearance times must be considered, and that appropriate clearance intervals must be computed and entered into the controller.

5.6   Fine-Tuning

Results from PASSER^{TM} III-98 should not, at face value, be interpreted as "correct" or one hundred percent optimal. The output from the program is subject to the limitations of the data that was input to the program. Even if all of the geometric details and signal information is correct, there exists an unavoidable stochastic element to traffic volume that can be managed, but not overcome. The best that can be accomplished is to develop a signal timing plan that can accommodate the most reasonable high-volume traffic scenario at any given site. Engineering judgement and field observation must always be a part of the field implementation process.

At all stages in the timing plan development process, input data and output results should be checked for accuracy and reasonableness. Any discrepancies or perceived errors should be investigated and resolved to the satisfaction of the traffic engineer ultimately responsible for timing plan implementation.

Once the PASSER^{TM} III-98 output has been translated into controller phase settings that can be entered in the field, these settings should be entered into the official files and/or databases that the agency uses to keep track of timing parameters at the intersections and interchanges for which it is responsible. Field technicians, after field coding the new timing plan, should observe operations to ensure that the intent and details of the new plan are properly achieved by the control devices in the field. This includes verification and fine-tuning of the controller/controllers' behavior, cycle length (if applicable), phase splits, and offsets (if applicable). Field tuning also involves determining the effects of the new timing plan on traffic flow. To assist with tracking the translation, implementation and monitoring of PASSER^{TM} III-98 output, Table 24 has been prepared as a checklist of important activities.

It should be noted that motorists require time to become accustomed to new timing plans. Accordingly, the "true" impact of timing plan changes is not likely to be readily apparent to observers. Once the new plan is input and verified, observations and measurements of its field performance should wait until drivers have become familiar with the new patterns. If the new timing plan differs significantly from previous signal operation or other interchanges in the vicinity, signs should be posted to alert drivers to changes in signal operation.

Table 24. Checklist for PASSER^{TM} III-98 Output Conversion to Controller Settings

Examination of PASSER^{TM} III-98 Output:

❒   Output report corresponds to desired cycle length, phase sequence, and left turn treatment
❒   No v/c ratios greater than 0.95 (if possible)
❒   No delays greater than LOS D (if possible)
❒   Delays equitably spread around the approaches of the interchange
❒   Phase times reasonable and appropriate for prevailing conditions
❒   No storage ratios greater than 0.8 (if possible)
❒   Pedestrian times taken into consideration
❒   Actuated settings calculated based on detection system (if applicable)

Translation of PASSER^{TM} III-98 Output into Controller Settings:

Dual Controllers:
❒   Appropriate phase numbering scheme developed for dual controller operation
❒   Each controller configured with a ring structure designed to produce desired settings
❒   Overlap definition and parent phases appropriately applied (if applicable)
❒   Offset chosen to produce correct phase sequence relationship within interchange
❒   Manual or computer simulation of settings produces desired timing plan
❒   Pedestrian times taken into consideration
❒   Plan reviewed and approved by a licensed traffic engineer

Single Controller:
❒   Appropriate phase numbering scheme developed for single controller operation
❒   Controller configured with a ring structure designed to produce desired settings
❒   Overlap definition and parent phases appropriately applied (if applicable)
❒   Manual or computer simulation of settings produces desired timing plan
❒   Pedestrian times taken into consideration
❒   Plan reviewed and approved by a licensed traffic engineer

Single Controller – Texas Diamond Controller (TDC) Specification:
❒   TDC phase numbering scheme used for single controller operation
❒   TDC configured with a ring structure designed to produce desired settings
❒   Overlap definition and parent phases appropriately applied (if applicable)
❒   Manual or computer simulation of settings produces desired timing plan
❒   TTI four-phase fixed interval transitions correctly entered as "transition intervals" (if applicable)
❒   Pedestrian times taken into consideration
❒   Plan reviewed and approved by a licensed traffic engineer

Field Implementation and Monitoring of Controller Settings

❒   Timing plan update information stored in agency files and/or databases
❒   Field hardware (controller, field wiring, signal heads, etc.) capable of accommodating timing plan
❒   Timing plan correctly rendered in field signal displays (by visual observation after settings are input)
❒   "After" study confirms timing plan reduced delay, stops, travel time, etc. (after motorist acclimation time)

DRAFT

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